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MINING AND BENEFICIATION OF APPALACHIAN MANGANESE ORES

BY

EDMUND NEWTON

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MINING AND BENEFICIATION OF APPALACHIAN MANGANESE ORES[1]

By Edmund Newton[2]

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2/ One of the consulting engineers, Bureau of Mines, U. S. Department of the Interior.

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INTRODUCTION

This paper is one of a series comprising the Mineral Industries Survey of the United States, which was begun in 1935. It describes the simple methods of mining and beneficiating manganese ores in eastern Tennessee and compares these methods with those used elsewhere in the Appalachian region. The report contains general information on manganese to give a clearer understanding of the methods and costs of mining and beneficiating manganese ore from a widespread deposit, and in addition presents some difficulties normally found in these operations.

The marketing, uses, and value of manganese ore are discussed as well as the amount of capital necessary for effective operation on a given scale of production, and requirements are outlined for successful operation of manganese property in this region.

As this paper is intended to assist the Bureau of Mines in answering the many requests for information on the production of Appalachian manganese ore made by laymen unfamiliar with mining, it has been written in as nontechnical language as possible.

ACKNOWLEDGMENTS

The author wishes to thank the operators and their staffs for their splendid cooperation in furnishing information for this circular. The assistance of N. E. Lewis, manager, and W. A. McCain, mine accountant, Embree Iron Co., is appreciated. Ellicott Wheeler, president of this company, kindly gave permission to publish data on his property.

Thanks are due A. Hamilton Wood, who, as consulting engineer of the East Tennessee Manganese Co., designed and constructed the plant for his help in collecting and preparing essential material for the description of this property. Thanks also are extended to J. S. Millard, president of the company for permission to publish information on this property.

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GENERAL INFORMATION ON MANGANESE

Uses of Manganese

The principal use of manganese is in the manufacture of steel. All ordinary steels require some manganese to give essential physical characteristics. No satisfactory substitutes for manganese have been found for this purpose. When large quantities of manganese are added to steel a manganese-steel alloy is formed which is very tough and resistant to abrasion.

During the 5-year period 1934 to 1938, inclusive, for each ton of steel produced in the United States the consumption of manganese ore for all purposes, calculated on the basis of manganese metal, was about 14 pounds. Thus, it is apparent that the demand for manganese varies roughly with the rate of steel production.

Since 1918 some steel plants have added manganese to the iron-blast-furnace ore mixture to give a higher manganese content to the iron used in making basic open-hearth steel than would be yielded from the available iron ores alone. Certain of the beneficial effects of manganese are gained in this way, and less ferro-manganese is required to finish the steel. This fact is important to producers of domestic manganese ore, because many ores that are unsuitable for manufacture of alloys can be used to increase the manganese content of basic iron.

The ceramic industry, the glass industry, and many chemical industries employ considerable manganese. Usually ores quite high in manganese are required, but various other properties control their suitability for a particular use. A very high grade ore is essential for the battery industry.

Classification of Manganese Ores

Manganese ore comprises four different raw materials, determined by grade and quality as follows:3/

1. Exceptionally high grade manganese ore characterized by a high content of MnO_2 is used in making batteries. It commands the highest unit price and is known as battery ore.

2. At the other extreme is manganiferous iron ore, usually containing 10 percent or less manganese; it is used for making manganiferous pig iron. The domestic supply of such ore is so abundant that the manganese it contains is usually paid for as if it were iron.

Between these two extremes are the ores low in iron that are suitable for making ferromanganese and those high in iron used for making spiegeleisen, although some of it is used for making pig iron.

3/ Finch, John W., Strategic Minerals Investigations; Procedure Followed by the Bureau of Mines: Bureau of Mines Inf. Circ. 7097, 1939, pp. 2-3.

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3. For making ferromanganese, the ore usually contains at least 45 percent manganese but averages 48 percent, and the ratio of manganese to iron is not less than 7 to 1 though it usually is 8 to 1, while there must be low silica (ranging from 7 to 10 percent) and very low phosphorus (ranging from 0.12 to 0.2 percent). Only manganese ore of this character has been designated as a strategic mineral because domestic production is inadequate.

4. Ore in which the manganese-iron ratio is too low for making ferromanganese can be used for making spiegeleisen. Of such manganese ores, high in iron, there is no deficiency, and a relatively low price is paid for the manganese they contain. Although an excess of silica often can be remedied by gravity concentration, iron is difficult to remove by that means because the specific gravities of iron and manganese oxides are so nearly the same.

The terms "metallurgical" and "chemical" ore are used to designate the industry in which it is used.

Ferromanganese. - Standard ferromanganese contains about 80 percent manganese and 12.5 percent iron and may be made in a blast furnace or an electric furnace. By either method some manganese is lost in the slag. If allowance is made for the average loss in good practice an ore mixture must have about nine times as much manganese as iron to yield 80 percent ferromanganese. For example, an ore containing 45 percent manganese and 5 percent iron would be suitable if other constituents were not detrimental.

A furnace making ferromanganese seldom uses a single ore but rather uses a mixture of ores of different chemical content. Thus, if some fairly high-grade manganese ore is available, a certain amount of material with a lower manganese content can be added to give the desired manganese-iron ratio to the furnace-ore mixture. Such blending of several ores may also improve the physical character of the mixture for furnace use.

Impurities in Manganese Ores. - In manganese ores such impurities as silica, alumina, lime, magnesia, and barium oxide form slag during metallurgical processes.

In the manufacture of ferro-alloys some slag is necessary metallurgically, but an excess of slag is undesirable. More coke is required to melt excess slag, and still more slag is formed by ash from this coke. Some manganese is lost by passing into the slag, the total loss being almost in direct proportion to the volume of slag.

Silica is the principal slag-forming impurity and metallurgically is the most objectionable one. A penalty usually is imposed by the purchaser if the silica in manganese ore exceeds a certain specified amount, in some instances 8 and in others 10 percent. Other impurities seldom are found in objectionable amounts in Appalachian manganese ores.

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Phosphorus is a very objectionable impurity in steel, causing it to be brittle. As all the phosphorus in manganese ore goes into the ferro-alloys made from it and so is added to the steel, certain limits for phosphorus in manganese ore usually are imposed by purchasers. If the ore contains more phosphorus than this specified limit, it may either be penalized (receive a lower price) or be rejected.

Almost any manganese-bearing material containing from a few percent to 35 or more, can be used effectively to increase the manganese content of basic iron. The choice of material depends mostly on the cost of available ore. A low phosphorus content is not as important as it is in manufacture of alloys, and materials quite high in phosphorus can be used, but materials low in phosphorus are preferable.

Manganese-ore Prices

All manganese ore, as received by the purchaser, contains some moisture, usually from a few percent to 10 or more. Manganese ore is bought on the basis of a long ton (2,240 pounds) of dry ore, so that the weight of the water must be deducted from the actual weight recorded. The amount of moisture is obtained by drying a representative sample at not more than 212° F. Manganese ore containing over 35 percent manganese is paid for on the manganese content alone. The price is quoted on a unit of manganese. A unit is 1 percent of a dry long ton or 22.4 pounds of metallic manganese. As an incentive to the production of ore with a high manganese content its price per unit is higher than that of ore containing less manganese. Occasionally, on ores carrying less than 35 percent manganese payments are made for units of both manganese and iron.

The following schedules are typical of those in force in April 1940:

Birmingham Metallurgical Ore

Manganese Ore. - The unit is a dry ton of 2,240 pounds, f.o.b. receiver's works, Birmingham, Ala.

Manganese, percent:	Cents per unit of manganese
26 to 29.99.....	30
30 to 34.99.....	40
35 to 39.99.....	45
40 to 44.99.....	50
45 and over.....	55

Another schedule for ore, containing from 18 to 20 percent manganese and 30 to 35 percent iron, is based upon payment for both manganese and iron, as follows:

Metal:	Cents per unit
Manganese.....	30
Iron.....	5 1/2

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Kingsport Chemical Ore

This ore is purchased upon the basis of units of manganese dioxide (MnO_2) contained in a dry ton of 2,000 pounds delivered at Kingsport, Tenn. Present contracts range from 40 to 50 cents per unit of dioxide.

Ore containing 70 percent or more manganese dioxide is desired. This is theoretically equivalent to 44.2 percent or more metallic manganese. With this manganese content the accompanying iron, silica, phosphorus, and other constituents in average Appalachian ores are satisfactory. Fine material is not objectionable, and rather soft ore is preferred.

Statistics on Manganese Ore

A very small part of the manganese consumed in the United States comes from domestic production; hence, on account of the need for it during national emergency, manganese (in higher-grade ores) is classed as a strategic metal. Table 1 gives data on domestic shipments, imports, and apparent consumption.

APPALACHIAN MANGANESE-ORE DEPOSITS

Geology

Manganese is widely distributed in the Appalachian region. Although it is associated with rocks of different geologic ages, by far the most productive ore deposits occur in Shady dolomite, an impure limestone of the Cambrian period of geologic time.

Some manganese-ore deposits, principally in western Virginia, occur in the Oriskany formation, which geologically is much younger. Most of these deposits were discovered in 1918, and they have yielded a comparatively small tonnage. The ore differs somewhat from that in the Shady dolomite in that it has more cherty silica and sand but less clay, as well as somewhat different manganese minerals; however, much the same practice is used in preparation for market.

Deposits in Shady Dolomite

Distribution. - Manganese-ore deposits occur at intervals in this formation along the west front of the Blue Ridge in Virginia,[4] in northeastern Tennessee,[5] and in Alabama. They also occur in the Cartersville district of northwestern Georgia.[6] In north-central Virginia the deposits extend from the vicinity of Front Royal in Warren County through Page, Rockingham,

4/ Stose, G. W., Miser, H. D., Katz, F. J., and Hewett, D. F., Manganese Deposits of the West Foot of the Blue Ridge, Va.: Virginia Geol. Survey, Bull. 17, 1919, pp. 22-24.

5/ Stose, G. W., and Schrader, F. C., Manganese Deposits of East Tennessee: Geol. Survey Bull. 737, 1923, 184 pp.

6/ Hull, J. P. D., LaForge, L., and Crane, W. R., Manganese Deposits of Georgia: Georgia Geol. Survey Bull. 35, 1919, pp. 215-222.

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Augusta, Rockbridge, and Botetourt Counties, almost to Roanoke.[7] Another area is in the three southwesterly counties of Virginia—Wythe, Smyth, and Washington – and in the three adjacent counties of northeastern Tennessee – Johnson, Carter, and Unicoi.

The manganese-ore deposits of the Cartersville district in Bartow County, Ga., lie in a narrow belt of Shady dolomite about 20 miles long.[8]

TABLE 1. – Domestic shipments of manganese ore, imports of manganese and ferromanganese, and apparent consumption of manganese metal, 1925-29 (average) and 1934-38, in long tons[1]

Year	Manganese ore			Imports of ferro-manganese (gross weight)	Apparent consumption of manganese metal[2]	
	Domestic shipments		Imports		Quantity	Percent from domestic sources
	10 to 35 percent Mn	35 percent or more Mn				
1925-29....	189,725	59,312	613,409	63,038	312,963	9.2
1934.....	23,231	26,514	341,339	23,349	3/	3/
1935.....	93,291	26,428	383,500	27,240	210,784	4.8
1936.....	98,962	32,119	813,362	37,953	310,497	4.1
1937.....	151,955	40,241	911,922	29,559	3/	3/
1938.....	33,620	25,321	483,588	26,258	217,961	6.1

1/ Ridgway, Robert H., and Davis, H. W., Manganese and Manganiferous Ores: Bureau of Mines Minerals Yearbook, 1939, p. 579.
2/ In ferromanganese and spiegeleisen.
3/ Bureau of Mines not at liberty to publish figures.

The number of mines and prospects that had been worked in the Shady dolomite before 1918, described in various publications, is as follows:

Location:	No.
Virginia - Blue Ridge...	82
Northeast Tennessee	55
Cartersville, Ga.....	70
Total.....	207

Structure. – In most places the structure of the original rocks before weathering and decay has determined the form and size of the deposits in Shady dolomite. Hewett and others[9] recognize at least five structural types, two of which are of primary economic importance;

7/ Hewett, D.F., Stose, G. W., Katz, F. J., and Miser, H. D., Possibilities for Manganese Ore on Certain Undeveloped Tracts in Shenandoah Valley, Va.: Geol. Survey Bull. 660-J, 1918, pp. 271-304.
8/ Rankin, H. S., Laurence, Robert A., and Davis, F. A. W., Manganese Resources of the Tennessee Valley Region: T. V. A. Geol. Bull. 7, 1938, p. 4.
9/ See footnote 7.

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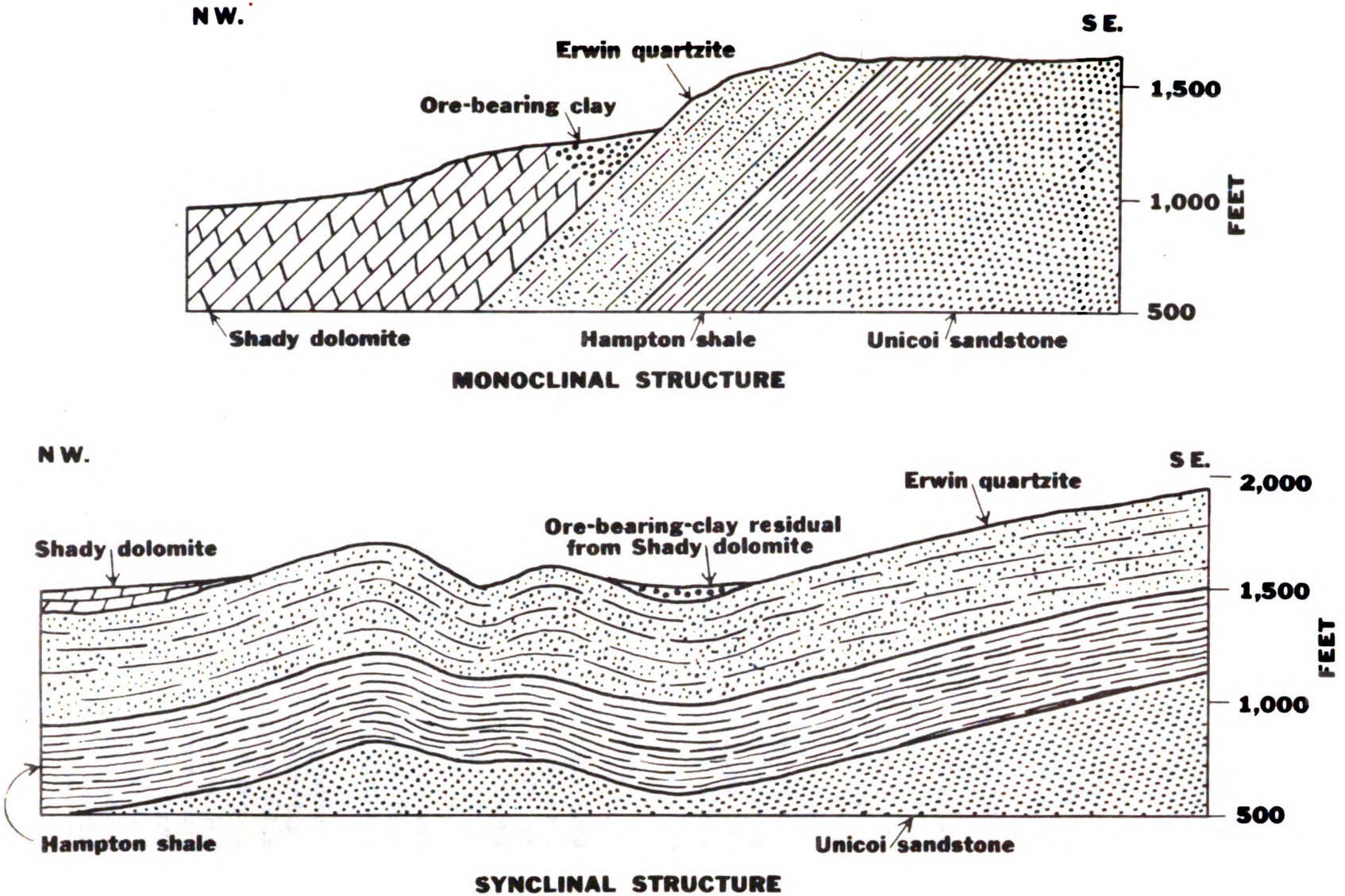

Figure 1.—Geologic sections of typical manganese deposits in the Shady dolomite. (After Geological Survey Bull. 737.)

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Figure 1, adapted from Hewett and others shows the most common form of deposit. In this deposit ore has accumulated on the weathered outcroppings of fairly steeply dipping beds of Shady dolomite at the foot of ridges composed of the harder, underlying formation known as Erwin quartzite. Stose and Schrader[10] state that virtually all such deposits in eastern Tennessee are now on benches, considerably above the present stream valleys. These benches are remnants of an old valley floor formed at the same time as the deposits and subsequently lowered by erosion.

Hewett and others[11] state that deposits of this type usually are comparatively small and that few have yielded 25,000 tons of ore whereas many have failed to produce as much as 5,000 tons before they were abandoned.

Another form of deposit occurs in clays that fill troughs on the upper surface of the Erwin quartzite, as shown on figure 1. Although at present few deposits of this type have been discovered, these conditions are most favorable to the formation of the larger, thicker deposits. The Crimora deposit in Virginia, from which about 167,000 tons of manganese ore has been produced, exemplifies this type. Hewett and others[12] state:

> Exploration of the deposit at the Crimora mine, which has has yielded more manganese than any other in the region east of the Allegheny Mountains, and of other deposits that have similar relations confirm the tentative conclusion that troughs in which the beds have low dips are the most-favored sites for the accumulation of ore.

This factor is important in planning exploratory work.

Character and Origin. - Manganese-ore deposits of this type usually lie in banded clay derived from the weathering and decay of impure beds of limestone, generally in the lower 200 feet of the formation. The ore consists essentially of heavy brown to black oxides of manganese, irregularly distributed as lumps or nodules of different sizes in clays resulting from the decay of sedimentary rocks. At and near the surface of most deposits are pebbles and fragments of rocks, usually quartzite and sandstone washed down from the mountainsides; these pebbles are mixed with the nodules in the clay. Iron oxides are almost always present in widely varying amounts.

The manganese is generally believed to have been deposited in some soluble form, probably as a carbonate, when these rocks were originally laid down; to have then been dissolved by the circulating surface waters which also decomposed the limestone; and finally to have been redeposited from solution, as oxides of manganese, in nearby residual clays. Occasionally these oxides formed in open spaces as lumps or nodules of various sizes and shapes. Frequently chemical replacement of the constituents of the clay has been rather complete. When complete, the nodules consist of almost pure manganese mineral; when imcomplete, they contain less manganese and have disseminated through them a skeleton of microscopic constituents of the original clay.

10/ See footnote 5.
11/ See footnote 7.
12/ See footnote 7.

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The degree of completeness of the replacement is important in beneficiation of the ore. Some masses of manganese oxides in these deposits are large and clean and require no preparation before shipment except sledging down to convenient size for handling. With this exception, all raw material requires some form of preliminary treatment before the ore can be shipped.

Manganese Minerals. - Manganese oxides closely resemble iron oxides, and their identity is often confused. Stose and Schrader[13] state that they may be distinguished readily in the field, as follows: When crushed to the form of powder, manganese oxides are dark brown to black, while one form of iron oxide (hematite) is reddish brown and another, probably the more common form (limonite), is yellowish brown.

Four manganese minerals are common in Shady dolomite ores. According to Stose and Schrader[14] often these cannot be identified positively without chemical analysis and other tests. For rough field identification, they give the following classification:

1. A manganese mineral that is hard, black or dark gray, and massive is classed as "psilomelane."

2. A mineral that is crystalline and fairly hard is usually termed "manganite", whereas one that is crystalline and soft is called "pyrolusite."

3. A mineral that is soft and granular but does not show the crystalline texture of pyrolusite or the firm, massive character of psilomelane usually is termed "wad."

These minerals are described in somewhat greater detail but, insofar as possible, in nontechnical language in the following pages.

Psilomelane (About $Mn_2O_3 \cdot H_2O$ + Ba and K)

Psilomelane is the commonest manganese mineral in the Shady dolomite ore. It is a bluish black to grayish black amorphous mineral of uncertain formula. Usually it has rounded surfaces and sometimes resembles bunches of grapes or heads of cauliflower; again it may take the form of stalactites, and occasionally it is nipple-shaped. The fractured surface resembles that of steel and often shows concentric layers of mineral; it is so hard that a knife will scratch it with difficulty, if at all. The powdered mineral is brownish black. The specific gravity ranges from 3.7 to 4.7.

The chemical composition of psilomelane is variable, and the formula is written in many ways. The formula given is that of Stose and Schrader.[15] Manganese may range from 45 to 60 percent but usually is between 50 and 57 percent. Some water of crystallization is always present, generally 2.5 to

13/ Stose, G.W., and Schrader, F. C., Manganese Deposits of East Tennessee: Geol. Survey Bull. 737, 1923, 154 pp.
14/ See footnote 13.
15/ See footnote 13.

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6 percent. This water must not be confused with moisture, which can be driven off at the boiling temperature, 212° F. Water of crystallization is chemically combined in the mineral, and much higher temperatures are necessary to drive it off. Psilomelane often contains barium oxide, sometimes as much as 15 percent, and in some specimens potassium is present.

Manganite ($Mn_2O_3.H_2O$)

Manganite is associated with psilomelane in many Shady dolomite manganese deposits, and generally its presence is regarded as an indication of high-grade ore.

It is a heavy, grayish black to black mineral and usually occurs in the form of crystals. It can be scratched readily with a knife but cannot be scratched with a brass pin. The powdered mineral is dark reddish brown or nearly black. The specific gravity ranges from 4.2 to 4.4.

The crystals of manganite are bladed, wedge-shaped, or needlelike. The crystal faces are black and usually have a brilliant metallic luster, but they may be tarnished to a brassy color. Manganite sometimes forms rounded masses of so-called needle ore. Nodules from many deposits are composed of alternating layers of psilomelane and needlelike, radiating crystals of manganite. Theoretically manganite contains 62.4 percent manganese and 10.3 percent water of crystallization.

Pyrolusite - MnO_2 (Generally with a Little H_2O)

Pyrolusite is a grayish black to black mineral with a crystalline or granular form. It is so soft that it can be scratched by the fingernail and readily soils the fingers. The crystals do not have a metallic luster. The powdered mineral is black, and the specific gravity is about 4.8.

Previously, pyrolusite was generally believed to have been formed from manganite by loss of water of crystallization, but recent work suggests that it formed originally as pyrolusite. Theoretically it contains 63.2 percent manganese, and the actual content ranges from 60 to 63 percent.

Wad

Wad is a soft, earthy mineral, generally considered to be an indefinite mixture of manganese oxides, with some water of crystallization and other impurities such as clay and oxides of barium and iron. For the most part, it occurs as a dry, dark-brown or black powder, closely resembling clay.

Wad contains 30 to 42 percent manganese, 7 to 10 percent water of crystallization, and usually barium oxide - sometimes in considerable quantities.

Associated Impurities

Clay. - Clay is the principal impurity in Shady dolomite manganese-ore deposits. Silica occurs in the clay as clean, visible particles of quartzite

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or chert and as finer grains of sand. In addition, the apparently clean nodules of manganese oxides contain different proportions of gangue materials so intimately mixed mechanically that they are invisible to the naked eye.

Iron and Phosphorus. - Iron oxides generally are present in manganese ore of this type, usually as limonite ($2Fe_2O_3.3H_2O$), often called "brown ore." The manganese and iron oxides occur either as a single lump, in which the two minerals can be distinguished, or so intimately mixed (either mechanically or chemically) that differentiation is impossible.

Phosphorus is present in varying amounts and frequently appears to be associated more closely with the iron minerals than with those of manganese.

Preparation for Market

Manganese-bearing material mined from Shady dolomite deposits contains too many impurities to be used without preliminary treatment before shipment.

This preliminary treatment is known as ore dressing. The term is applied to separation of the valuable minerals from the impurities by using certain of their physical properties. It is an intermediate step between mining and metallurgical processes. In ore dressing the valuable mineral is termed "concentrate," whereas the impurity removed is termed "tailing." A broader term for the complete treatment process is "beneficiation."

The physical properties on which the preliminary treatment of Shady dolomite manganese ore depends are: Size of particle, appearance, hardness, and specific gravity. These physical properties are the basis of the simple ore-dressing practices of washing, screening, hand picking, jigging, and table treatment.16/

Elsewhere in the United States and in some foreign countries other physical properties are being utilized successfully to beneficiate manganese ores. These properties include magnetic permeability, upon which magnetic separation is based, and certain surface characteristics of minerals that make flotation possible. In some districts the volatile impurities such as water, either in the form of atmospheric moisture or water of crystallization, and carbon dioxide in carbonate ores are driven off by heating or roasting. Not only are these impurities removed and the manganese content of the remaind correspondingly increased, but also the process can be controlled so that the iron minerals are converted into a more highly magnetic form that is more favorable for magnetic separation. Whether or not the more complex ore-dressi processes based upon these physical properties can be used successfully on manganese-bearing material from Shady dolomite deposits is a problem of economics rather than technology.

The physical properties controlling the treatment of Appalachian manganese ores are described briefly as follows:

16/ DeVaney, Fred D., and Coghill, Will H., Occurrence and Ore-dressing Possibilities of Ores of Manganese in the United States: Bureau of Mines Inf. Circ. 6768, pt. 1, ch. 4, May 1934, 98 pp.

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Size of Particle. - Clay is by far the most prevalent impurity. The particles of clay are very fine and when mixed with water stay in suspension. When the liquid is poured off, the clay is removed from the clean particles of manganese mineral and coarse impurities. This is the basis of washing and is the customary first step in the preliminary treatment of most Shady dolomite ores.

Hardness. - The coarse lumps of most Appalachian manganese minerals owe their size to their hardness, although this does not always apply to pyrolusite. With some ores this characteristic can be used to give a concentrate high enough in manganese to ship and a clean tailing by merely passing the material over a single screen with the proper size of opening. Even if the concentrate is not high enough to ship, screening often is used as a preliminary step before making use of the physical properties of appearance and specific gravity.

Appearance. - When the clay has been removed by washing, the light-colored waste rock can be distinguished from the manganese minerals, which are dark-colored, and either can be removed by hand picking. Sometimes only the waste is removed, but occasionally large pieces of ore that appear to be particularly high in manganese also are taken out and sold for chemical purposes.

Hand picking can be done most easily when the pieces of material are larger and usually the finer particles of the washed ore are screened out before such treatment. The size of screen opening to be used is largely a matter of balancing cost and results.

Specific Gravity. - Specific gravity is the ratio of the weight of a unit volume of a substance to the weight of the same volume of water. As stated, the specific gravity of most manganese minerals in Shady dolomite deposits ranges from 3.7 to 4.8, whereas the specific gravity of silica in the form of pure chert is only 2.65. This difference in the specific gravity of the valuable mineral and the waste is used in a group of ore-dressing processes that are termed "gravity concentration."

The usual methods of gravity concentration are known as jigging and tabling. Jigging ordinarily is applied to moderately coarse particles through the use of vertical currents of water, whereas tabling is applied to finer material through the use of horizontal currents of water.

The fundamental factors for successful application of gravity-concentration processes are that the mineral particles shall have a specific gravity at least 1 1/2 times that of the waste and that the particles of mineral and waste shall be as near the same size as possible.

Application of the gravity-concentration processes to ores from certain deposits in the Shady dolomite are discussed in greater detail later.

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Economic Possibilities. - These are well-summarized by Stose and others[17] as follows:

> Although most of the deposits of the Blue Ridge region of Virginia do not appear to be large, many deposits are known, and in the aggregate they are capable of yielding a large quantity of ore. Although small pockets are rapidly worked-out and abandoned, new ones are commonly discovered nearby.
>
> Though considerable prospecting and exploration has been done and is now being done, it is not at all unlikely that many deposits still remain to be discovered, some of which may prove to be large.

OPERATIONS OF EMBREE IRON CO., NEAR EMBREEVILLE, TENN

General

For many years the Embree Iron Co., formerly of Chicago, Ill., and more recently of Easton, Md., operated iron mines and a blast furnace in the Bumpass Cove district of northeastern Tennessee. This area is about 3 miles southwest of Embreeville, partly in Unicoi County and partly in Washington County, Tenn., as shown clearly in figures 2 and 3.

The iron operation has long been abandoned, but lead and zinc deposits found in the area before 1918 are still being operated by the company.

During the World War a manganese deposit was discovered on the northwest slope of Bumpass Cove, and considerable prospecting was done in 1918 under the stimulus of high prices for manganese ores. Owing to the collapse of the manganese market at the close of the war little, if any, ore was produced.

During the past few years this deposit has been prospected extensively by underground work and drilling. After part of the area had been drilled systematically with a churn drill, plans were made to begin power-shovel mining, and modern equipment was installed in a washing plant near the ore deposit and in a concentrating plant near the lead-zinc concentrators in Bumpass Cove.

In 1939 the Embree Iron Co. produced 7,348.5 tons of washed and concentrated ore containing more than 35 percent manganese, of which 7,158.6 tons was shipped. Of the ore shipped, 6,640.6 tons went to Birmingham, Ala., for use as metallurgical ore and 518.0 tons to Kingsport, Tenn., for chemical purposes. As the average annual production of metallurgical ore containing more than 35 percent manganese for Alabama, Georgia, Tennessee, and Virginia totaled only about 7,200 long tons during the 5 years preceding 1939, the importance of the Embree operation is apparent.

17/ Stose, G. W., Miser, H. D., Katz, F. J., and Hewett, D. F., Manganese Deposits of the West Foot of the Blue Ridge, Va.: Virginia Geol. Survey Bull. 17, 1919, p. 48.

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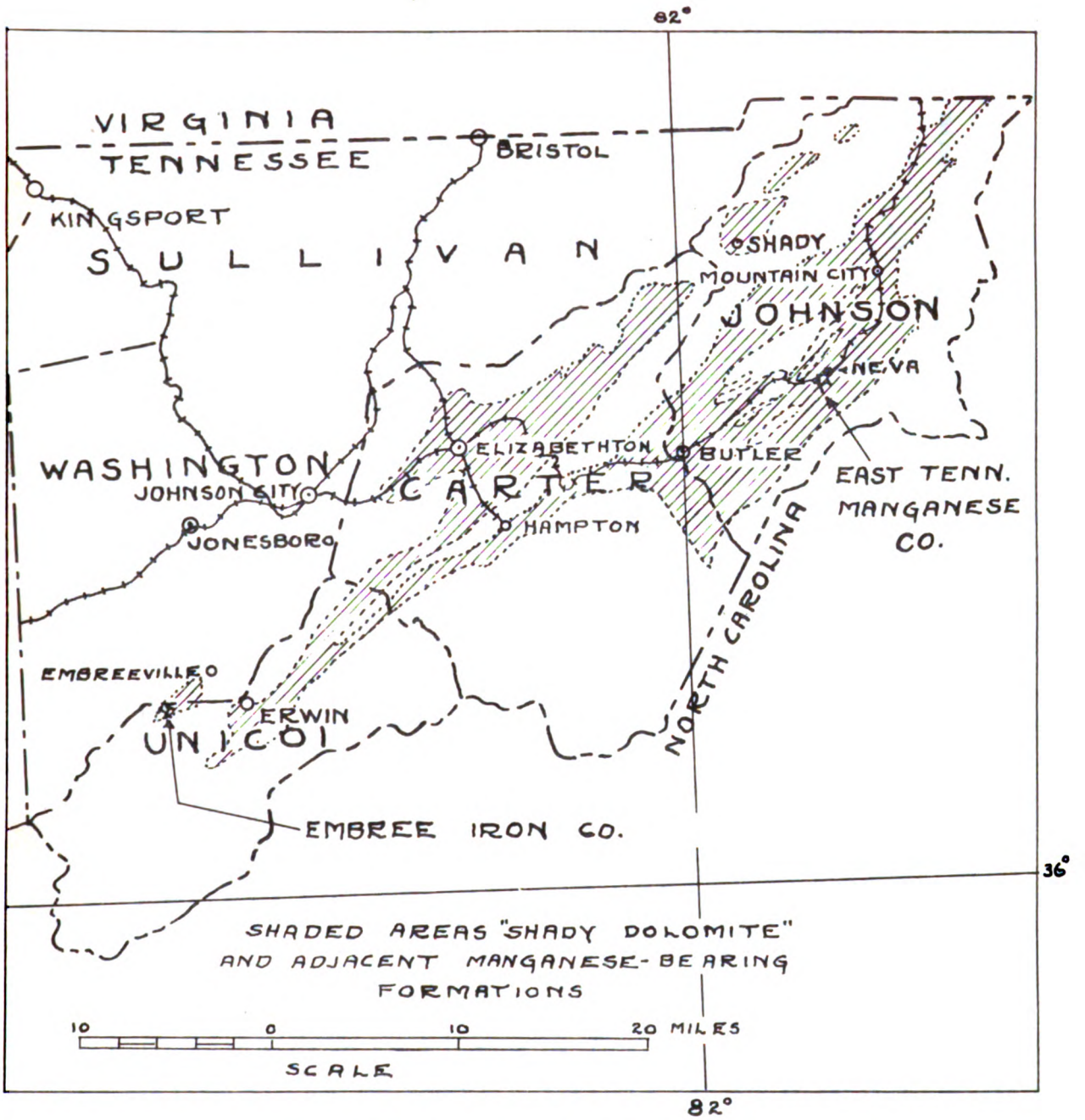

Figure 2.—Location of certain manganese properties in northeast Tennessee. (After Geological Survey Bull. 737.)

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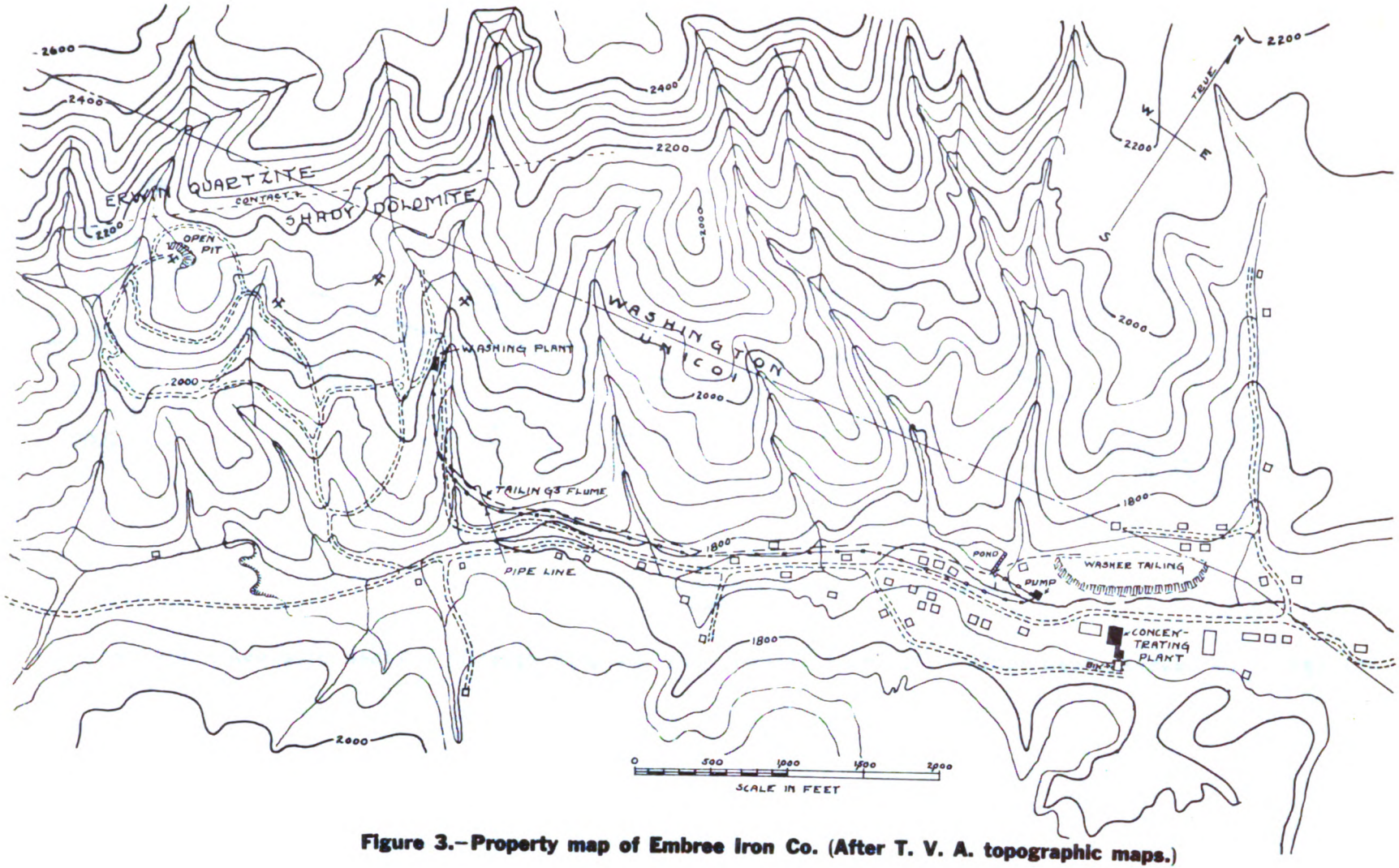

Figure 3.—Property map of Embree Iron Co. (After T. V. A. topographic maps.)

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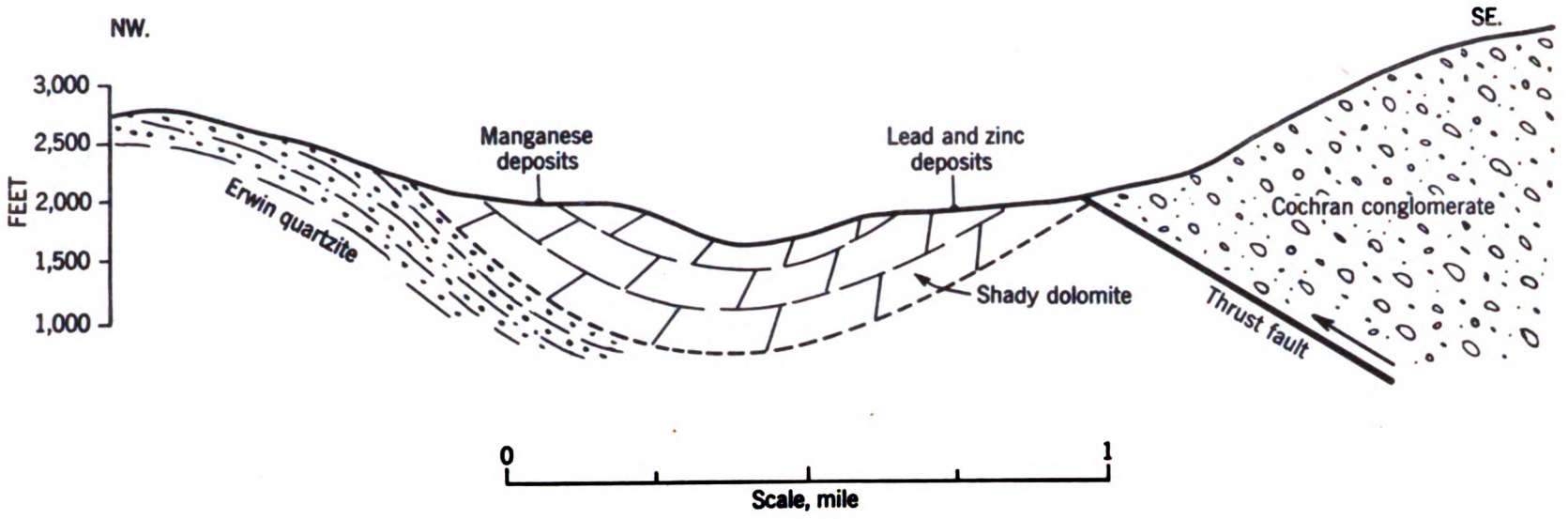

Figure 4.- Geologic section through Bumpass Cove, Embree Iron Co. (After Geol. Survey Bull. 737.)

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It is believed that a detailed description of the equipment and practice of the Embree Iron Co., and results obtained by the company in mining and treating a residual manganese deposit in the Shady dolomite of the Appalachian region will be of constructive interest to those who may be contemplating a manganese operation in a deposit of the same general type.

Ore Deposits

The following data on the geology have been compiled from the work of Stose and Schrader.18/

The Bumpass Cove district, which contains the Embree manganese deposits, is a faulted synclinal valley in which the Shady dolomite lies on the Erwin quartzite. To the southwest a thrust fault has brought an older bed of conglomerate in contact with the Shady dolomite. These relations are shown in plan and section in figures 3 and 4, adapted from Stose and Schrader.19/

The manganese deposits are on the northwest side of Bumpass Cove at an altitude of about 2,160 feet; they lie several hundred feet above the present bottom of the cove on a bench which is a remnant of an old valley floor.

The ore occurs in dark-red or yellowish residual clay which has resulted from the decay of Shady dolomite, close to the contact with Erwin quartzite. The contact dips about 45° southeast.

The manganese-bearing residual clay underlies a fairly thick mantle of surface wash, which contains more iron than clay and numerous pebbles or fragments of quartzite and sandstone that have been eroded from higher elevations. In some places, at least, the phosphorus content of this surface wash is higher than that of the underlying manganese ore.

The manganese-ore deposits trend northeast-southwest, generally parallel to the strike of the country rock. Early prospecting was done at irregular intervals for nearly half a mile. Pits, shafts, and open-cuts rarely exceeded a depth of 20 feet, which was not enough to penetrate the surface wash on the terraces overlying the thicker manganese deposits.

Bank ore, which is the term used for material as dug from the ground, consists essentially of nodules, softer lumps, and lighter, porous particles of psilomelane irregularly distributed throughout clay of different colors. Bank ore also contains considerable soft, black material, locally called "plumbago," which is essentially pyrolusite and wad.

The predominant waste material in the bank ore is clay. The clay can be separated from the ore effectively by treatment in a log washer. After the clay is removed the washed ore usually contains much chert or quartzite, with small grains of sandstone, from the surface wash overlying the residual clays.

18/ Stose, G. W., and Schrader, F. C., Manganese Deposits of East Tennessee: Geol. Survey Bull. 737, 1923, 184 pp.

19/ See footnote 18.

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Besides this visible, cherty silica the apparently clean nodules or particles of manganese oxides contain many exceedingly fine particles of silica and associated waste material, which can be detected only under a microscope.

Part of the iron appears to occur as individual grains of limonite, but part is very intimately associated with the manganese oxides either as a mechanical mixture or in chemical combination.

The nature of the phosphorus and its relationship to the other minerals is not clear. Apparently, in many deposits it is closely related to the cherty, iron-bearing phases of the surface wash and upper parts of the deposit.

Analyses of Clean Manganese Ore. - The following table gives complete analyses of selected samples of high-grade ore.

Analyses of selected samples of clean manganese ore, percent

	1	2	3	4	Average
Manganese oxide (MnO)...	5.18	5.97	2.68	4.04	4.47
Manganese dioxide (MnO_2)	65.40	73.32	64.84	55.45	64.75
Ferric oxide (Fe_2O_3)....	9.07	4.33	14.49	13.92	10.45
Phosphorus.....	.150	.176	.110	.092	.132
Silica (SiO_2).....	7.80	4.70	6.06	14.30	8.21
Alumina (Al_2O_3).....	.99	.78	1.15	1.38	1.08
Barium oxide (BaO).....	2.58	2.08	2.49	2.35	2.37
Potash (K_2O)	.05	.00	.06	.08	.05
Molecular water (H_2O)1/.	8.78	8.64	8.12	8.39	8.49
Total.....	100.00	100.00	100.00	100.00	100.00
Total manganese.....	45.32	50.92	43.08	38.12	44.41
Total iron.....	6.33	3.03	10.10	9.75	7.32
Total iron and manganese	51.65	53.95	53.18	47.87	51.73

1/ Determined by difference; also referred to as water of crystallization.

Exploration

During the past few years the Embree Iron Co. has used churn drilling in advance of mining to indicate the size and shape of the ore bodies and to show variations in the recovery and grade of concentrate that might be expected from various parts of the ore body.

Because the ore deposits lie high on the steep slopes of a mountain it is impractical to locate churn-drill holes according to a regular checkerboard pattern. A caterpillar tractor and a bulldozer with an angling blade are used to build roads for churn-drill stations, which are approximately 50 feet apart horizontally.

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Figure 5.- Embree Iron Co.; view of power-shovel loading truck in open pit.

Figure 6.- Embree Iron Co.; view of washing plant.

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Churn-drill holes are rarely over 40 feet deep. The clay stands well, and usually the holes are not cased. The sampling interval is 4 feet. Relatively little water is used in drilling, and a very thick sludge is removed by the bailer. Every 4 feet this sludge is dumped into a tub and mixed thoroughly with a shovel.

A representative sample of the sludge weighing several pounds is placed in a suitable sample can and sent to the laboratory. This sample is weighed wet and the percentage of moisture determined. The clay is then washed off and the resulting concentrate dried and weighed. From these data the "bulk recovery" or ratio of concentration is obtained.

The remainder of sludge from the 4-foot interval is then diluted with water and thoroughly stirred, and the muddy water is decanted. This process is repeated until only granular particles of ore and gangue remain. These are labeled properly and sent to the laboratory for inspection and analysis.

This procedure yields data on the recovery and grade of concentrate that could be obtained from a log washer but gives no clue as to the amount of silica present in such form that it might be removed by subsequent jigging. To determine this the author suggests that, in churn-drilling manganese-bearing material of this general type a representative sample of the dry, washed drill cuttings be weighed and tested with a "heavy solution," such as acetylene tetrabromide with a specific gravity of 2.95. The products, which sink and float on this liquid, could then be washed with benzol, dried, weighed, and analyzed for manganese and other constituents if desired.

From these data the grade and percentage by weight of the washed concentrate recoverable by jigging could be determined. This procedure accords with that used by the Bureau of Mines for testing manganese ores. Fred D. DeVaney, in a letter to the author, states that the method accurately forecasts results from jigging.

The drill data are then plotted to scale on sections, and a schedule of power-shovel mining is planned. These sections show where it is desirable to remove layers of high-iron, high-silica, and high-phosphorus surface wash, and transport them to a waste dump rather than send them to the washing plant. They also are the basis for intelligent planning and building of roads over which the bank ore can be hauled in dump trucks from the power shovel to the washing plant.

Mining

At the Embree Iron Co. operation bank ore was excavated with a "Loraine 45" power shovel, equipped with a 3/4-cubic yard dipper, driven by a gasoline engine, and mounted on crawler treads.

The material was easy to dig and did not have to be broken with explosive ahead of the shovel. The shovel loaded light dump trucks with 2 1/2-cubic yard bodies. (See fig. 5.) One 8-hour shift usually is sufficient to keep the washing plant supplied with bank ore.

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Labor. - The operating crew in the open pit is as follows: One pit foreman, one shovel operator, one bulldozer operator, and one roustabout or oiler.

Transportation to Washing Plant

The washing plant is approximately 0.65 mile by road from the pit where the shovel is now working and about 160 feet lower in elevation than the present floor of the pit. Usually four dump trucks are required to haul waste and to carry bank ore to the washing plant.

From frequent weighings of truckloads of this material 2.5 dry tons has been accepted as the average dry weight per load. A record of the number of truckloads delivered to the washing plant is kept each day so that a fairly accurate figure is obtained for the dry tons of bank ore fed to the washing plant.

Washing Plant

Location. - Figure 3 shows the location of the washing plant with respect to the present pit and the concentrating plant. A general view of the plant is given in figure 6, which shows a hose sluicing down ore in the storage bin.

Flow Sheet. - Figure 7 indicates the flow of material through the plant.

Lay-out. - Figure 8 gives the general arrangement of the equipment in the washing plant.

Storage Bin. - Bank ore is dumped from trucks into an open storage bin on the hillside, as shown in figure 6. This bin has a length of 48 feet, along which the trucks dump. The sides and bottom are built of plank supported by round timbers. For a short distance below the dumping point the bottom of the pocket slopes about 45°. The rest of the pocket has a bottom slope of about 30°. The ore will not slide on this section until sluiced with water. Consequently, enough bank ore can be stored during one shift of open-pit operation to keep the washing plant supplied with feed for three shifts.

Grizzly. - On the bottom of this pocket is a horizontal grizzly 42 feet long by 8 feet wide. The screening surface is heavy screen wire with 3 1/2-inch square openings between 5/8-inch rods. Several 60-pound rails, placed lengthwise of the grizzly on cross timbers, support the grizzly screen.

At the end of the grizzly, toward the log washer, is a section about 10 feet long and 4 feet wide constructed of 60-pound rails set upside down and about 1 inch apart. In this section large lumps of waste or ore are sledged to convenient size for handling in chutes.

Water under pressure, from a nozzle attached to a hose, sluices the feet from the storage bin to the grizzly. Underneath the grizzly is a watertight, V-shaped hopper, the bottom of which slopes toward the log washer.

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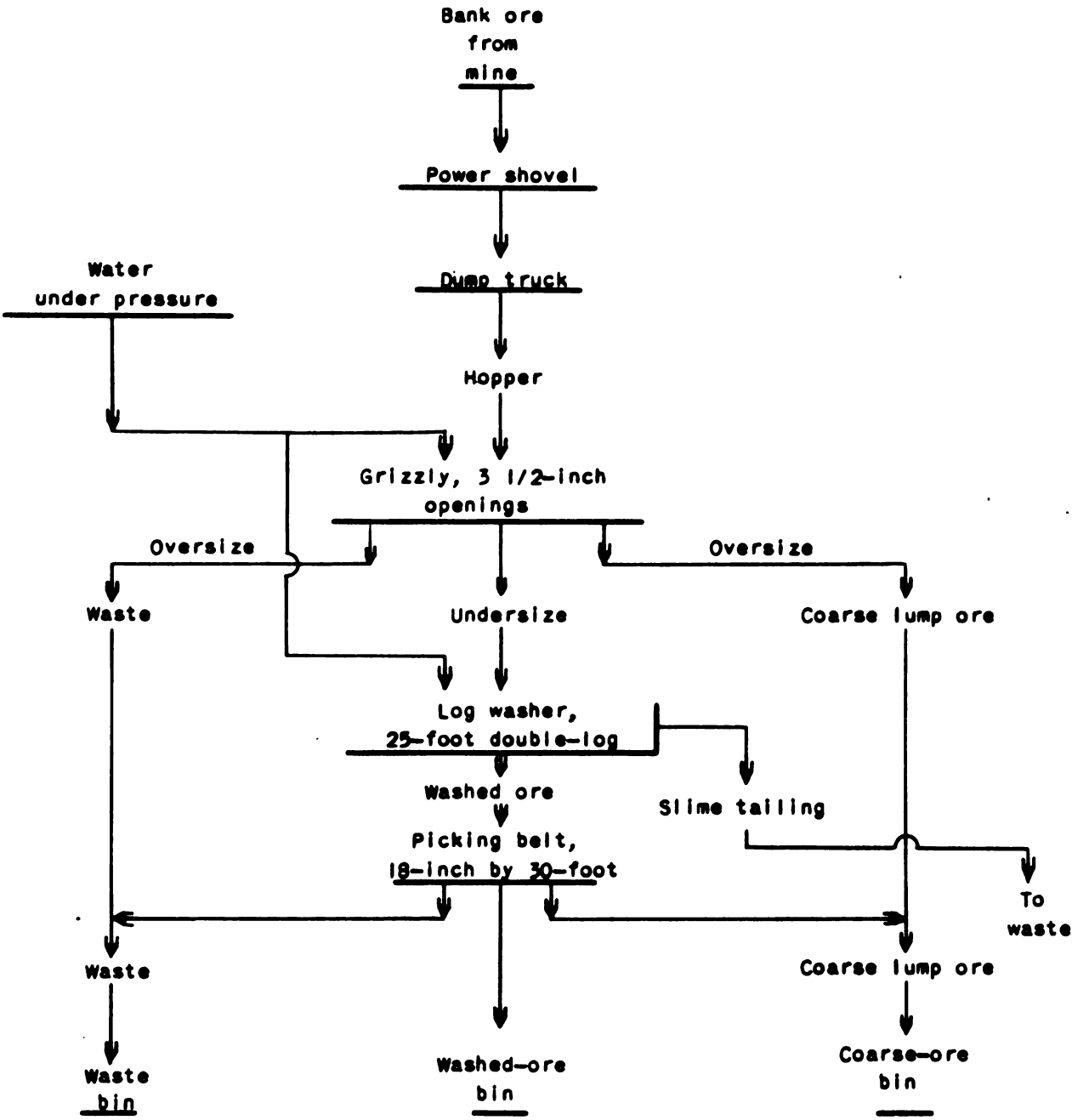

Figure 7.- Embree Iron Co., flow sheet of washing plant.

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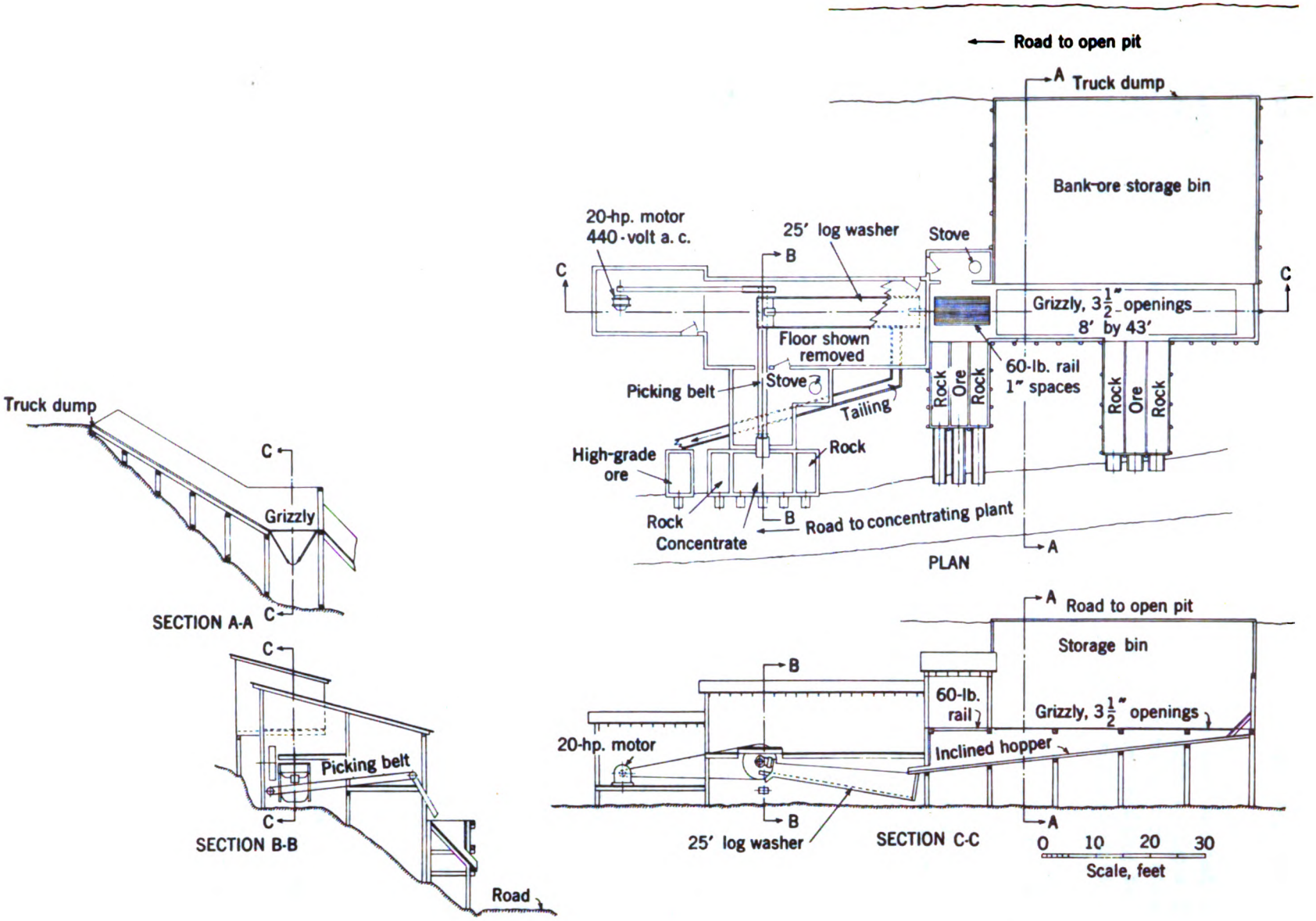

Figure 8.- General lay-out of washing plant, Embree Iron Co.

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This sloping hopper carries the fine material passing the grizzly openings and the water to the feed point of the log-washer box.

Large lumps that could not pass the grizzly openings were washed clean with the hose. If these lumps were high-grade ore, they were sledged to the proper size for shipment and thrown into a chute leading to an ore storage bin. If they were waste rock they were thrown into a chute leading to a waste bin. Lumps that were part ore and part waste were sledged until they passed the grizzly openings.

Usually three men are employed at the grizzly, although the number varies with the character of material.

Log Washer. - A 25-foot, double-log washer with integral steel box is used. The washer is described in the section comparing Northeastern Tennessee ore-treatment practice with that of other Appalachian districts.

The bottom of the log-washer box slopes 2 inches per foot, and the logs have a speed of about 18 r.p.m. The feed enters the log-washer box in the center and about 2 feet from the lower end.

The log-washer concentrate is sprayed with clear wash water along the final 8 feet of the logs before it is discharged. This concentrate goes direct to a picking belt without screening. The muddy overflow from the rear end of the log washer flows for a short distance in a ditch alongside the road to the concentrating plant and then in a wooden flume to the settling pond shown in figure 3. The mud settles in this pond, and clear water overflows into the stream.

Picking Belt. - The picking belt is 18 inches wide and about 28 feet long. It is set with a slight inclination toward the tail end and is at right angles to the long axis of the log washer. The speed of the belt is about 30 feet per minute. The management states that a belt of greater length would be desirable. (See fig. 8.) Four men usually pick rock or high-grade ore from this belt, as required. The ore must contain 70 percent MnO_2 and is sent to Kingsport for chemical use.

Labor. - The usual operating crew at the washing plant comprised the following: One foreman, three men on the grizzly, and four men on the picking belt.

Water. - The washing plant required from 500 to 600 gallons of water per minute. This water was pumped about 4,500 feet through a 5-inch spiral-welded pipe with flexible couplings. The water was raised a vertical distance of about 260 feet from the main pumping plant in Bumpass Cove, as shown in figure 3.

A 5-inch, two-stage centrifugal pump, direct-connected to a 150-horsepower motor, supplied water for the washing plant. Meter readings in 1939 indicated that an average of 145 horsepower was required while the washing plant was in operation. A total of 363,100 Kw.-hr. was used during the year, or about 32 Kw.-hr. per ton of washer concentrate produced.

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Power. - Power was transmitted to the washing plant at 6,600 volts and there transformed to 440 volts. The log washer and picking belt at the washing plant were driven by a 20-horsepower, 440-volt, three-phase motor. A recording meter indicated the actual power consumed by this motor. In 1939 an average of 19 horsepower was used while the plant was operating. A total of 36,900 Kw.-hr. was used throughout the year, or about 3.25 Kw.-hr. per dry long ton of washer concentrate produced.

Capacity. - During 1939 the washing plant operated 3,831.5 hours - an average of about 73.7 hours per week or two shifts about every other day. When the bank ore gave a low recovery of washer concentrate, it was necessary to operate the washer three shifts a day.

The washing plant was fed with 68,990 dry long tons of raw material in 1939. Based upon 3,831.5 hours of operation, the feed averaged about 18 tons per hour or 144 tons per 8-hour shift. During the year, 11,355 dry long tons of washer concentrate was produced, or an average of about 3 tons per hour. These figures indicate that about 6 tons of bank ore is concentrated into 1 ton of washer concentrate, or as usually expressed, that the approximate ratio of concentration is 6:1.

Concentrating Plant

Location. - The concentrating plant (fig. 9) is on the valley floor of Bumpass Cove. (See fig. 3) It is about 1.0 mile from the washing plant and 260 feet lower in elevation. Nearby are the company plants for concentrating lead and zinc, shops, pumping plant, dwellings, and other operating facilities

Flow Sheet. - Figure 10 indicates the flow of material through the concentrating plant.

Lay-out. - The general arrangement of equipment is shown in figure 11. Because the building used to house the manganese concentrating equipment was formerly used as a concentrating plant for zinc ore, it was considerably larger than necessary.

Storage Bin. - The hand-picked log-washer concentrate was transported by truck from the washing plant to the concentrating plant, where it was dumped into an open storage bin similar to the bin used at the washing plant. A dump truck of the same size and type as the trucks used between the open pit and the washing plant hauled the concentrate and the hand-picked high-grade ore. Because the ore could be stored in this bin, the concentrating plant was able to operate intermittently, depending on production at the washing plant.

Feed Belt. - Ore was fed uniformly from the storage bin through a chute to a belt conveyor by means of an ingenious, home-made, adjustable gate. This close control was very important for the satisfactory operation of the concentrating plant.

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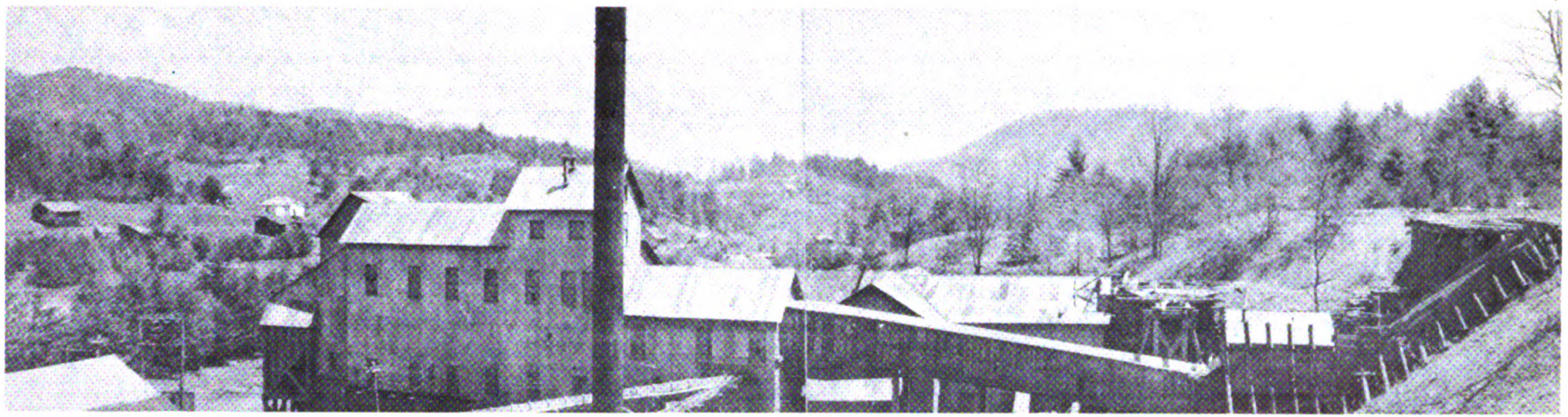

Figure 9.- View of concentrating plant, Embree Iron Co.

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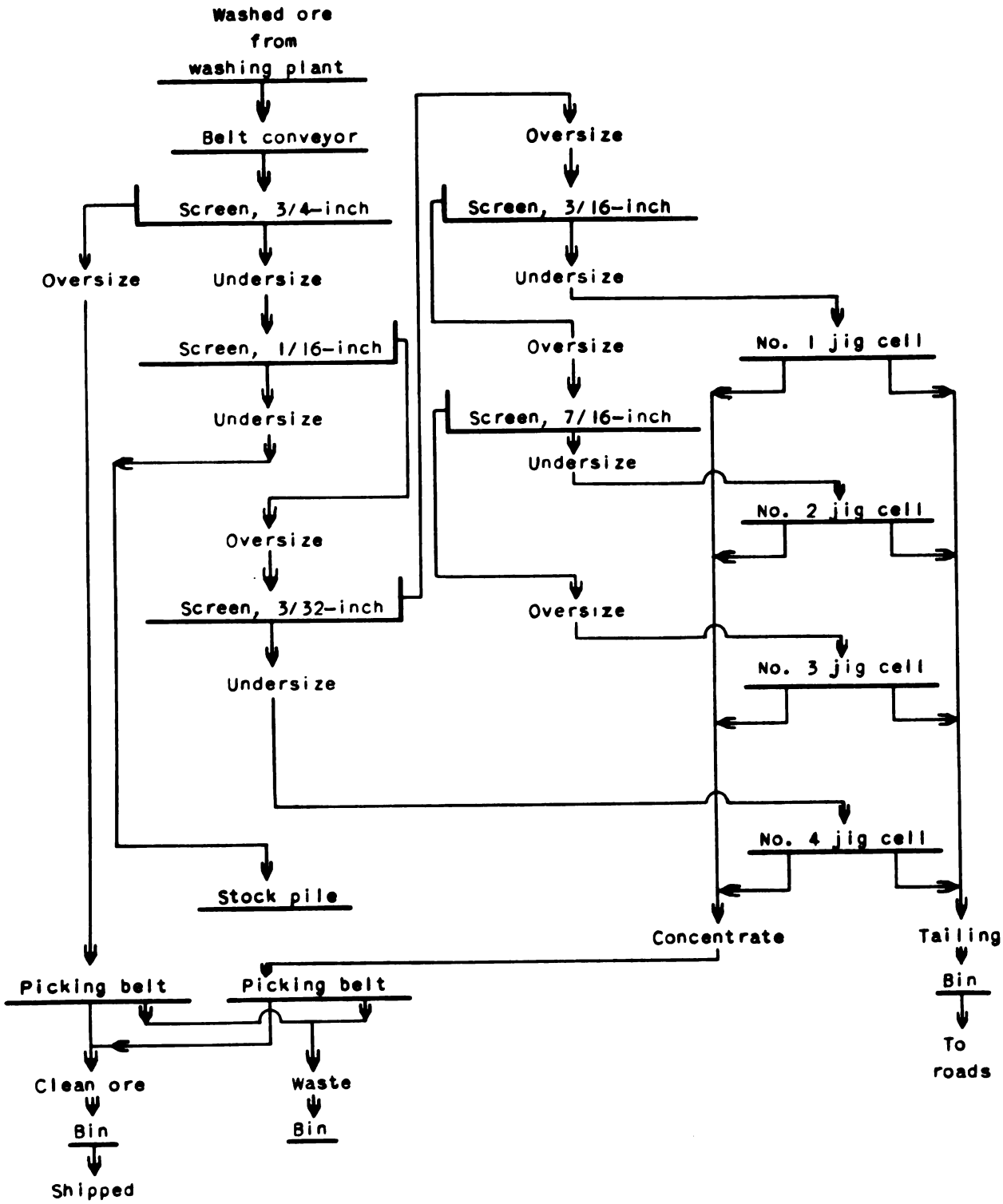

Figure 10.- Embree Iron Co., flow sheet of concentrating plant.

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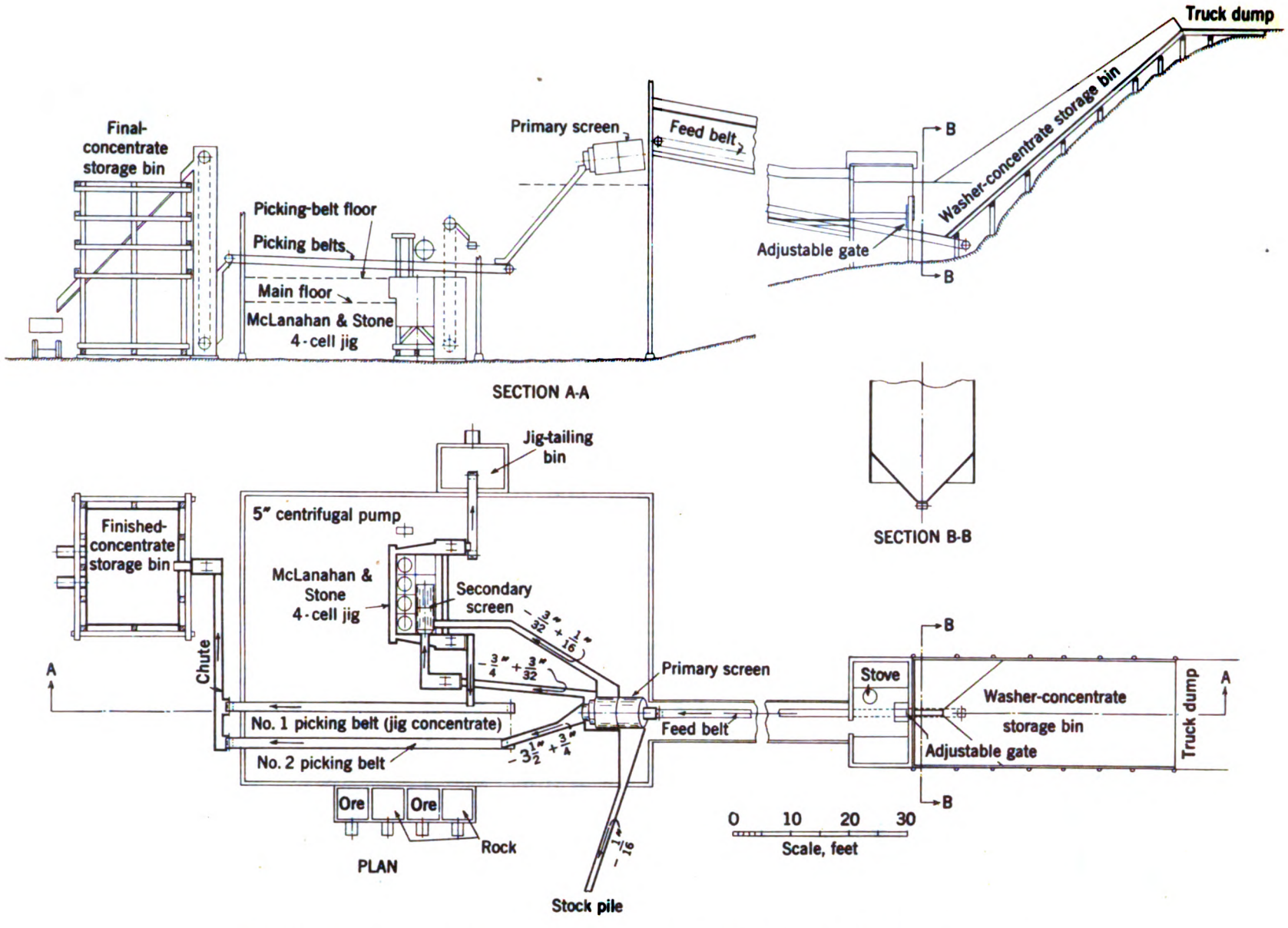

Figure 11.- General lay-out of concentrating plant, Embree Iron Co.

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The feed discharged through the gate to an 18-inch conveyor, which was about 100 feet long and had 14-inch head and tail pulleys. The belt was set at a slope of about 10° and traveled about 60 feet per minute. The discharge from the belt went to the primary screen.

Primary Screen. - The primary screen was a cylindrical trommel equipped with three concentric screens having openings of different sizes. This screen was set on a slope of 1 1/4 inches per foot and turned at 10 r.p.m. The feed from the belt entered the inner screen, which was 36 inches in diameter and 10 feet in length and was covered with wire screen having openings of about 3/4-inch. A change to 5/8-inch openings was being considered.

Surrounding the inner screen was another, covered with 1/4-inch wire screen which was 44 inches in diameter and 9 feet 6 inches in length. The outside section was 52 inches in diameter and 9 feet in length. Half the length of this screen, near the feed end, was covered with screen having slotted 1/16-by 1/4-inch openings. The other half was covered with screen having slotted 3/32- by 1/4-inch openings. A water spray was directed against the outside section of the trommel.

The oversize of the 3/4-inch inner screen flowed by gravity down a chute to a picking belt designated as No. 2. The undersize of the 1/16- by 1/4-inch slotted screen flowed in a launder to a stock pile outside the building. Some test work has been done on further treatment of this material. Its manganese content can be raised almost to the grade of concentrate now being shipped, but owing to its fineness it is not as suitable for use in steel-making plants.

The material that is coarser than 1/16-inch but goes through the 3/32- by 1/4-inch slotted openings of the last part of the outer shell flows by launder direct to the feed box of the No. 4 cell of the McLanahan & Stone jig.

All intermediate sizes, comprising particles that pass the 3/4-inch and remain on the 3/32-inch screen, flow through a chute to the boot of a bucket elevator, whence they are discharged into the secondary screen mounted directly over the first three jig cells.

Secondary Screen. - The secondary screen is a cylindrical trommel 42 inches in diameter and 8 feet in length. The first half has 3/16-inch round holes, whereas the second half has 7/16-inch round holes.

The undersize through the 3/16-inch holes falls directly into the feed box of the No. 1 jig cell. The undersize through the 7/16-inch holes is fed to the No. 2 cell, whereas the oversize goes to the No. 3 cell.

Jigging. - The concentrating plant of the Embree Iron Co. uses a McLanahan & Stone, 4-cell "pulsion" jig. Each cell of this jig is 48 inches long by 27 inches wide. Photographs, drawings, and descriptive matter presented later indicate how this jig operates and how it differs from the usual Harz-type jig often used in other Appalachian manganese districts.

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At the Embree plant, in accordance with the usual practice, each of the four cells of the jig receives a separate, closely-sized feed. To clarify the previous description of the preparation of feed to each cell by screening, the following summary is given of the size of particle fed:

Jig cell No:	Sizes of round holes in perforated-plate screen, 32ds inch
1.....	Minus 6 and plus 3
2.....	Minus 14 and plus 6
3.....	Minus 24 and plus 14
4.....	Minus 3 and plus 2

For each cell the openings in the jig-bed screens are smaller than the smallest particle fed to the cell. In other words, no hutch product is made[20] except the small amount of fines produced by abrasion. Valves are provided in the hutch for the material that falls through the bed screens so that it can be drawn off occasionally and saved when it is high enough in grade.

The size of openings in the jig-bed screens follows:

Jig cell No:	Size of opening in jig-bed screen
1	10-mesh wire screen, rear half 18-mesh wire screen, front half
2	1/8-inch punched plate, round holes
3	3/3-inch punched plate, round holes
4	Same as No. 1 cell

The feed to each cell enters the jig bed at the rear. The upward, pulsating current of water produced by the plungers causes the heavier particles to settle near the bed screen, where they gradually work their way across the screen to the front or discharge side. At the front, adjustable discharge gates draw off the heavy particles into an inclined chute, which slopes to the boot of a bucket elevator at one end of the jig; thus the heavy particles or concentrate produced by all four cells are combined as they are discharged by the bucket elevator. The buckets of the elevator are perforated so that the concentrate is drained before being discharged.

At the Embree plant the bucket elevator discharges the combined jig concentrate onto a separate picking belt.

The lighter particles of waste or tailing rise to the top of the jig bed and move across to the front of the bed, where they are discharged over the top of the concentrate chute into another chute, which slopes toward the opposite end of the jig. A similar bucket elevator at this end raises and dewaters them. At the Embree plant the jig tailing is discharged from the elevator onto a belt conveyor, which transports it to a storage bin.

20/ See discussions of jigging in the last part of this paper.

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No attempt was made at the Embree plant to pick from the tailings conveyor particles of ore that were not separated by the jig. It is doubtful whether the value of the material recovered would justify the cost of hand picking.

Jig tailing was drawn from this bin and stock-piled, pending possible future treatment. Some jig tailing, however, was spread on the road to the washing plant and the open pit and improved the roads for hauling in wet weather.

Hand Picking. - The ore was hand-picked on two separate picking belts. Both belts were nearly horizontal, rising only enough toward the discharge end so that water drained off the tail end. Both picking belts were 18 inches wide and were set with the center lines about 6 feet apart. They traveled about 30 feet per minute and were driven from the same tail shaft.

The picking belt designated as No. 1 received the combined jig concentrate. As all this material had passed the 5/8-inch screen and usually contained little waste, generally only one man was needed to pick from it.

The picking belt designated as No. 2 received the lump material which had passed the 3 1/2-inch openings of the grizzly at the washing plant and had remained on the 3/4-inch primary screen at the concentrating plant. Pieces of waste rock were picked off, usually by three men, and thrown into convenient waste chutes which emptied into a waste bin. These men also picked off pieces of high-grade chemical ore, which went to an appropriate bin. As the quantity of waste in the material that came to this belt varied from time to time the number of men picking from the belt was changed accordingly.

Labor. - The usual operating crew at the concentrating plant comprised the following: One mill superintendent, one adjustable-gate tender, four men on the picking belts, one jigman, and one oiler.

Water. - The concentrating plant used about 200 gallons of water per minute. A 5-inch, single-stage centrifugal pump, driven by the motor that operated the jig, drew water from a reservoir and distributed it throughout the concentrating plant at a pressure of about 35 pounds per square inch.

Power. - All equipment in the concentrating plant was driven by flat belts from pulleys on countershafts by three separate 440-volt, 3-phase, 60-cycle alternating-current motors. The connected load in the plant comprised the following motors:

	Motor horsepower
Feed belt conveyor, primary screen, picking belts, and main bucket elevator.....	15
Jig and 5-inch centrifugal pump.....	50
Bucket elevator from picking belts to concentrate storage bin.....	5
Total.....	70

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Meter readings during 1939 indicated that an average of 49 horsepower was required to operate the plant, of which about 18 horsepower was used by the jig. During the year, 122,232 Kw.-hr. was used, or 16.6 Kw.-hr. per ton for the 7,348.5 dry long tons of finished concentrate.

Capacity. - The concentrating plant was run only when necessary to treat the material delivered by the washing plant. In 1939 it was operated 1,144.5 hours, or about 30 percent of the time the washing plant was operated.

The total of 1,144.5 hours represented an average of about 22 hours a week. During the year the concentrating plant was fed 11,417 dry long tons of washer concentrate, or at the rate of virtually 10 tons per hour of operation.

General

At the Embree Iron Co. the washing plant is relatively close to the open pit, where the bank ore is mined. The washing plant is approximately 1 mile from the concentrating plant. Obviously, with a ratio of concentration of 6 to 1 it was more economical to pump 500 or 600 gallons of water per minute up to the washing plant than to truck the 5 tons of clay eliminated for each ton of washed concentrate produced the mile to the concentrating plant.

One reason, of course, why the Embree Iron Co. erected its concentrating plant in the valley was because the lead and zinc concentrators, shops, pumping plant, dwellings, and other operating facilities were already there. Moreover, they were able to use a building to house the manganese concentrating equipment that had formerly been used as a lead concentrator.

Although local conditions undoubtedly have controlled the separate location of washing and concentrating plants for the Embree Iron Co., a similar subdivision of operations may be desirable economically at other manganese operations in the Shady dolomite.

Power

Power for the manganese operation of the Embree Iron Co. is purchased from the Tennessee Eastern Electric Co. The power is generated at Greenville, Tenn., and transmitted through a substation at Erwin at 6,600 volts to the company operation, where it is transformed to 440 volts for motors and 110 volts for lights.

During 1939 a total of 522,232 Kw.-hr. was used by the manganese operation. This power cost $6,455.76, or an average of 1.236 cents per Kilowatt-hour. Based upon a production of 7,348.5 dry long tons of finished concentrate, 71.1 Kw.-hr. was required per ton produced. This power was distributed as follows:

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Washing plant:	Total Kw.-hr.	Total cost	Average horsepower	Final concentrate, per dry long ton Kw.-hr.	Cost
Main-water-supply pump....	363,100	$4,488.59	145.0	49.5	$0.6105
Log washer and picking belt	36,900	456.15	19.0	5.0	.0626
Subtotal.....	400,000	$4,944.74	164.0	54.5	0.6731
Concentrating plant:					
All equipment.....	122,232	$1,511.02	49.0	16.6	.2054
Total.....	522,232	6,455.76	213.0	71.1	0.8785

Sampling and Analyses

The various products are sampled according to accepted good practice. All analyses are made in the company laboratory situated near the main office in Embreeville.

No attempt was made to sample bank ore before it went to the washing plant or tailing, which comprised clay and fine sand removed by the washing plant.

The following products were sampled and analyzed each day:

Washing plant concentrate.[21]
Concentrating-plant feed.[22]
Undersize of 1/16- by 1/4-inch screen.
No. 1 picking-belt product, jig concentrate.
No. 2 picking-belt product, oversize of 3/4-inch screen.
No. 1 and No. 2 picking-belt products (combined).
Jig tailing, No. 1 cell.
Jig tailing, No. 2 cell.
Jig tailing, No. 3 cell.
Jig tailing, No. 4 cell.
Jig tailing, combined, from all cells.

In addition to the daily analysis of the foregoing products, each carload of metallurgical and chemical ore, as shipped, was sampled and analyzed for manganese, silica, iron, and moisture. The daily samples also were analyzed for the same constituents, except the jig-tailing samples, which were analyzed for manganese alone. Occasionally barium oxide (BaO) was determined, as about 2 percent of this constituent usually was present in the finished concentrate.

Confirmation analyses of each carload of manganese ore shipped to the Tennessee Coal, Iron & Railroad Co. were made by that company on manganese, silica, iron, alumina, phosphorus, and moisture.

21/ This sample applied to the tonnage produced by the washing plant.
22/ This sample was taken from the belt conveyor actually feeding material to the concentrating plant. The material probably was produced by the washing plant some days previously.

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Haulage of Concentrate to Shipping Point

Finished concentrate is hauled about 12 miles in the company dump trucks, from the bins at the concentrating plant to Jonesboro, Tenn., where it is shipped over the Southern Railway.

Railroad cars are spotted, and the trucks are backed up a ramp and dumped directly into them. It costs about $0.50 per ton to haul shipping ore 12 miles and load the cars in this manner. In accounting, these items are included in "General Expense," as shown later.

Freight Rates

The following freight rates on metallurgical ore are now in force from Jonesboro, Tenn., to Birmingham, Ala.:

Manganese, percent:	Freight per gross ton
42.99 and under.....	$1.80
43.00 and over.....	2.90

The freight rate is $1.00 per net ton of 2,000 pounds from Jonesboro, Tenn., to Kingsport, Tenn. During 1939, 320 net tons of ore was shipped by rail to Kingsport. Beginning in May of that year the remaining 198 tons was sent through by company trucks with an average load of 5.6 tons per truck. The distance from the concentrating plant to Kingsport is about 38 miles.

Operating Results, 1939

The following operating results have been obtained from the company records, with certain assumptions and adjustments as noted:

Washing plant. - The washing plant was fed 68,990 dry long tons of bank ore, which yielded 11,355 dry long tons of washed ore. The latter had the following weighted average analysis:

	Percent
Manganese	30.43
Silica.....	21.65
Iron.....	13.97

The washed ore represented 16.46 percent, by weight, of the original bank ore, and the corresponding ratio of concentration was 6:1.

As neither the bank ore nor the tailing from the washing plant was sampled and analyzed it is impossible to compute the recovery of manganese at this stage of the process. In January 1939, one sample of log-washer overflow showed 6.04 percent manganese. Another sample taken in February showed 10.75 percent manganese. A sample taken early in May 1940 showed about 2 percent manganese and 17 percent iron. This sample had a density of about 10 percent solids by weight.

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Concentrating Plant. - Although 11,355 dry long tons of washed ore was produced in 1939 by the washing plant, records show that 11,417 dry long tons was fed to the concentrating plant. The difference represented material drawn from reserve in the bin.

Concentrating-plant results for 1939

	Weight, percent	Dry long tons	Product, percent			
			Manganese	Silica	Iron	Manganese by weight
Feed[1]	100.00	11,417	30.43	21.65	13.97	100.00
Jig-and-belt concentrate	59.85	6,831	38.47	10.39	12.28	75.62
Chemical ore	4.50	518	47.25	8.05	4.95	7.05
Combined concentrate	64.35	7,349	39.90	10.22	11.76	82.67
Screenings, 1/16-inch[2]	12.50	1,427	23.20	34.00	10.00	9.54
Jig tailing and rock[3]	23.15	2,641	10.24	46.78	22.26	7.79
Combined tailing	35.65	4,068	14.78	42.39	17.95	17.33

1/ Washed ore, or concentrate, from washing plant.
2/ This percentage assumed to give a reasonable figure for the analysis of combined "Jig tailing and rock," which has been obtained by difference.
3/ Obtained by difference. The arithmetical average of jig tailing, for 114 days, showed 14.90 percent manganese.

Metallurgical ore shipped to Birmingham in 1939
(Weighted average of 132 carloads of metallurgical ore shipped to Birmingham, percent)

Month	Dry long tons	Manganese	Silica	Iron	Moisture
January	516.95	37.04	11.72	12.75	7.18
February	364.78	38.20	9.61	12.40	8.19
March	627.60	38.02	11.23	12.56	8.04
April	511.18	37.16	11.53	11.36	9.77
May	900.29	38.82	10.88	11.26	9.47
June	452.57	35.94	12.62	12.69	8.77
July	755.23	36.40	11.90	14.25	9.46
August	482.17	37.12	9.77	15.22	8.55
September	566.63	42.14	8.28	10.25	7.55
October	561.32	41.14	10.08	9.89	7.55
November	555.82	40.97	8.65	12.10	7.04
December	346.08	38.40	7.98	13.50	7.24
Total	6,640.62	.....	.....	.....	.....
Average	.....	38.47	10.39	12.28	8.34

The arithmetical average for the 132 cars was 38.56 percent manganese compared with the weighted average of 38.47 percent. These figures are so

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close that for convenience the arithmetical average of smelter returns on 131 carloads only was computed. A comparison of the arithmetical average of the smelter returns with the weighted average follows:

	Embree	Smelter
Manganese.....percent...	38.47	38.31
Silica.....do.....	10.39	10.51
Iron.....do.....	12.28	11.95
Phosphorus.....do.....	--	.161
Alumina.....do.....	--	2.53
Moisture.....do.....	8.34	8.47

Metallurgical Use. - A communication from the Tennessee Coal, Iron & Railroad Co. states that when the Embree ore contains more than 40 percent manganese it is used mainly in the manufacture of ferromanganese. Most of the ore which contains less than 40 percent manganese, is used in the iron blast furnaces to increase the manganese content of basic iron.

According to results of sampling and analysis by the Embree Iron Co., 42 of the 132 carloads shipped to the Tennessee Coal, Iron & Railroad Co. in 1939 (about 30 percent) contained more than 40 percent manganese.

OPERATIONS OF EAST TENNESSEE MANGANESE CO. NEAR NEVA, TENN.

General

The East Tennessee Manganese Co. was organized in 1939 to develop and operate the Wilson Hill property, near Neva, Tenn. This property was opened in 1918, and some ore was produced before the end of the war. It has laid idle since that time.

Early in 1940 construction was begun on a washing and concentrating plant. About the middle of April the first ore was fed to the plant. After the usual tuning-up period the plant operated satisfactorily.

This operation is based upon careful exploratory drilling, power-shovel mining, and treatment in a modern washing and concentrating plant. The equipment in this plant, although arranged in a different manner, is similar to that used by the Embree Iron Co.

As the plant has been operating so short a time, operating data would not be representative of work accomplished in a longer period.

Property

The Wilson Hill property lies in the Butler district, in the south-central part of Johnson County. It is about 8 miles southwest of Mountain City and about 1 mile south of Neva, a station on the Southern Railway. It is about 35 miles by air line from the Embree Iron Co. property. Figure 2

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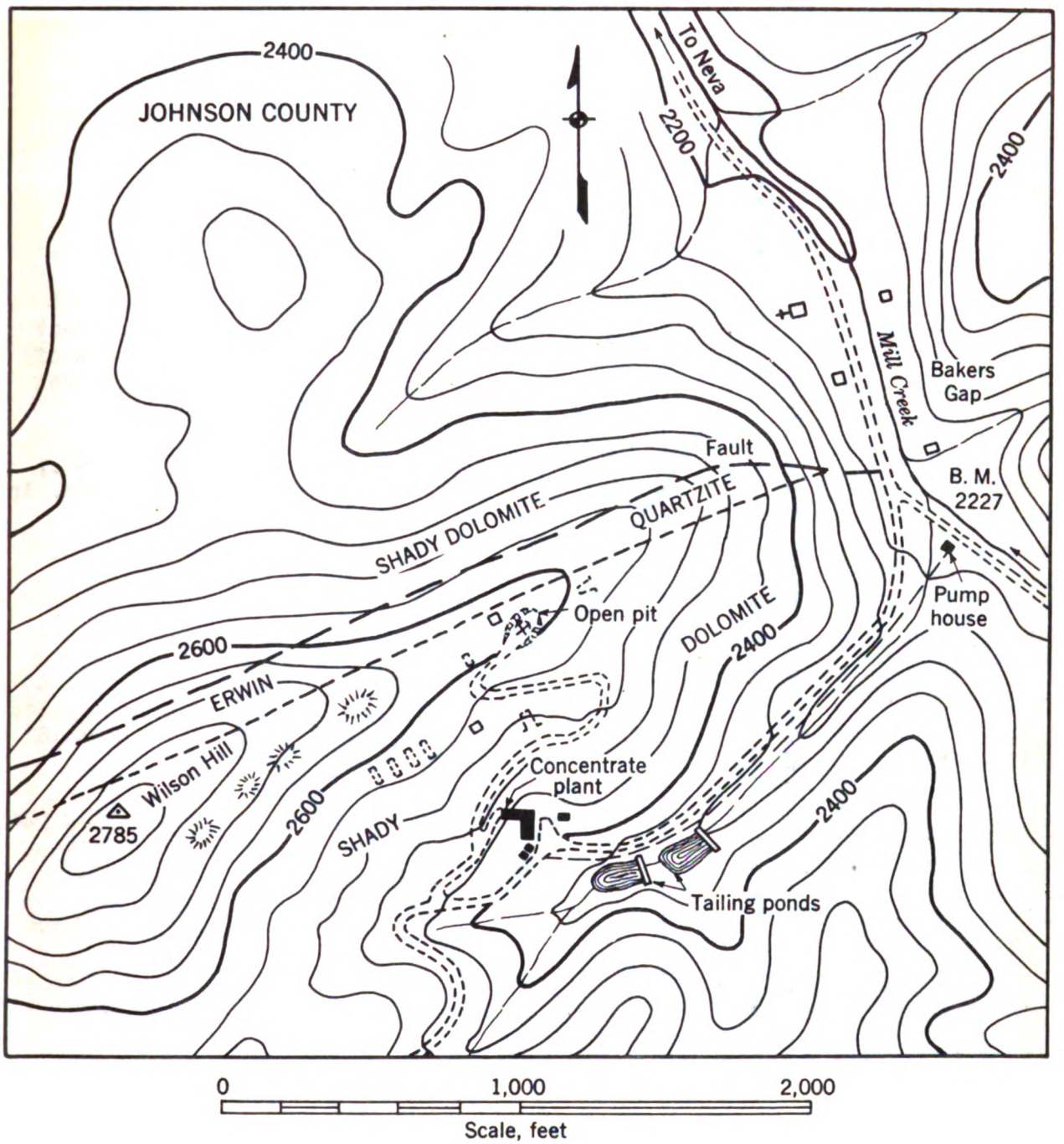

Figure 12.- Topographic sketch map, East Tennessee Manganese Co.

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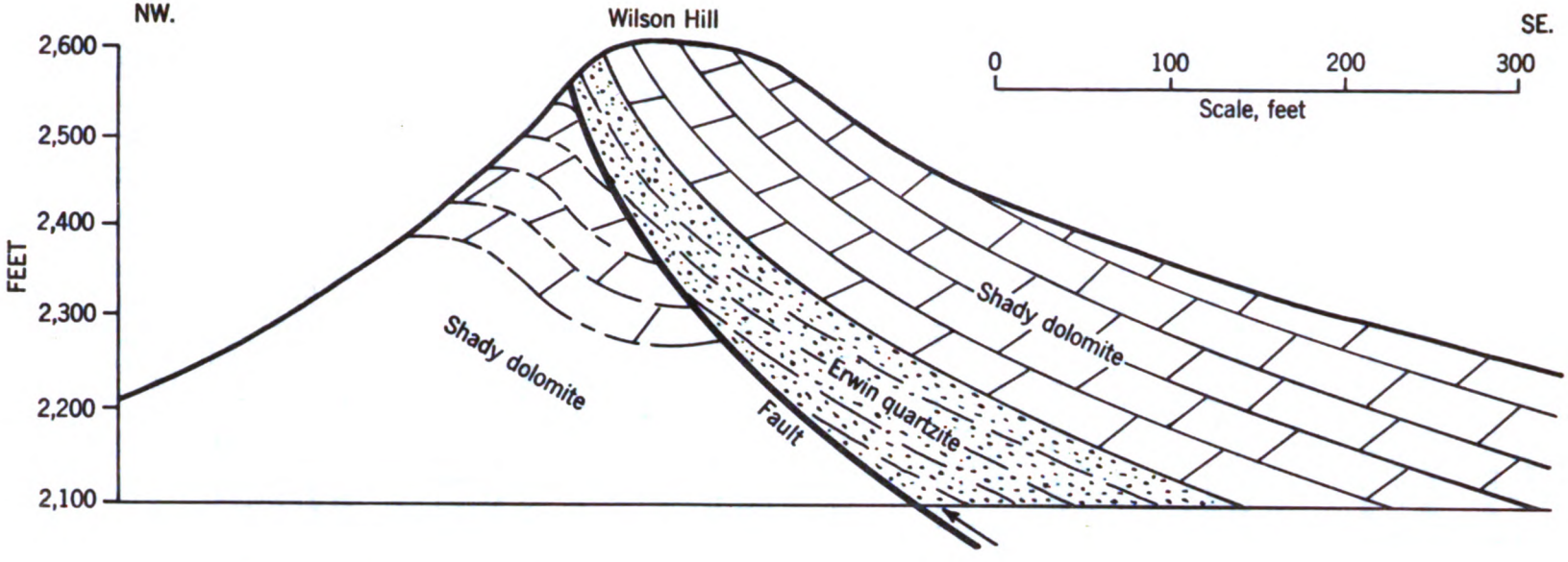

Figure 13.- Geologic section through Wilson Hill, East Tennessee Manganese Co.
(After Geol. Survey Bull. 737.)

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indicates location of the Wilson Hill property, and figure 12 is a topographic sketch map of the property of the East Tennessee Manganese Co.

The Wilson Hill property is held under lease by the East Tennessee Manganese Co. The royalty is based upon a sliding scale that depends on the grade and sale price of the finished concentrate.

Ore Deposits

The manganese deposits on the Wilson Hill property occur in the Shady dolomite formation. The following data are based upon the description given by Stose and Schrader.[23]

The manganese deposits occur along the top of Wilson Hill, a high, outlying ridge at the northeastern end of Dry Run Mountain. The ridge is about 1 mile long and about 2,800 feet high, whereas the floor of the main valley, in which Neva lies, has an elevation of about 2,150 feet. The manganese deposits occur on the southeastern slope of the ridge, at elevations of 2,400 to 2,800 feet. They occur chiefly in the clay and chert derived from the weathering of Shady dolomite close to its contact with the underlying Erwin quartzite.

The geologic structure is shown in figure 13 - a section at right angles to the ridge.

The ore comprises somewhat impure nodular psilomelane, considerable soft pyrolusite or wad, and some manganite. The nodules generally occur in bands of clay that are alternately yellowish and dark brown due to the wad. The clay contains much visible, cherty silica.

Exploration

Prospecting and exploratory work were active in 1918. In the summer of that year Stose and Schrader[24] found 12 or more prospect openings spaced at intervals along the top of the ridge for about 2,000 feet from the northeast end. They state that farther to the southwest iron is abundant and was mined in earlier days.

Most of the workings in 1918 comprised shallow shafts, pits, trenches, and larger open-cuts, of which some were 30 feet deep. Figure 12 shows their approximate location. The map was obtained by enlarging recent topographic sheets of the Tennessee Valley Authority. The prospect openings shown on the sketch map of Stose and Schrader[25] have been plotted on this map.

23/ Stose, G. W., and Schrader, F. C., Manganese Deposits of East Tennessee: Geol. Survey Bull. 737, 1923, 184 pp.
24/ See footnote 23.
25/ See footnote 23.

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During the latter part of 1939, 18 churn-drill holes having an average depth of about 40 feet were put down near the main pit of the 1918 workings. These holes were arranged in checkerboard form at the corners of 50-foot squares. Three holes were drilled below the road at the washing plant. Material from each 4-foot section was screened and washed separately. The percentage recovery by weight was then computed, and the washed ore was analyzed for manganese, iron, silica, and phosphorus.

Holes were drilled under contract by a driller from Embreeville, Tenn., who furnished the drill rig. The price was $1.25 per foot of hole. Enough ore was proved in the area drilled to justify the installation of equipment for mining and preparation of the ore for market.

Mining

A new "Northwest" 3/4-cubic yard, gasoline-driven power shovel is used for mining. This shovel has been equipped with a 5/8-cubic yard dipper. (See fig. 14.)

The shovel readily excavates the bank ore without shooting and loads it into dump trucks. These trucks have 2 1/2-cubic yard bodies and are of the same size and type as those used at the Embree operation. One 8-hour shift in the open pit can supply the washing and concentrating plant with enough bank ore for 24 hours operation.

Labor. - The present operating crew in the open pit follows: One shovel operator, one bulldozer operator,[26] and one roustabout or oiler.

Transportation to Washing and Concentrating Plant

The distance from the open pit to the storage pocket at the washing and concentrating plant is approximately 1,900 feet (0.36 mile). A new road from the open pit to the plant was built with the bulldozer. This road has a grade of approximately 10 percent. Usually three dump trucks haul bank ore from the open pit to the treatment plant.

Washing and Concentrating Plant

General. - The washing and concentrating units are combined in one plant at the East Tennessee Manganese Co. instead of being separated, as at the Embree Iron Co. (See fig. 15 and 16.)

Location. - Figure 12 shows the location of the plant and open pit.

Flow Sheet. - Figure 17 indicates the flow of material through the plant.

Lay-out. - The general arrangement of equipment is shown in figure 18.

[26] The bulldozer is also used on the roads and during the two shifts, when the open pit is not working, pushes the ore piled on the level platform into the storage bin at the plant.

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Figure 14.- East Tennessee Manganese Co.; power shovel in open pit.

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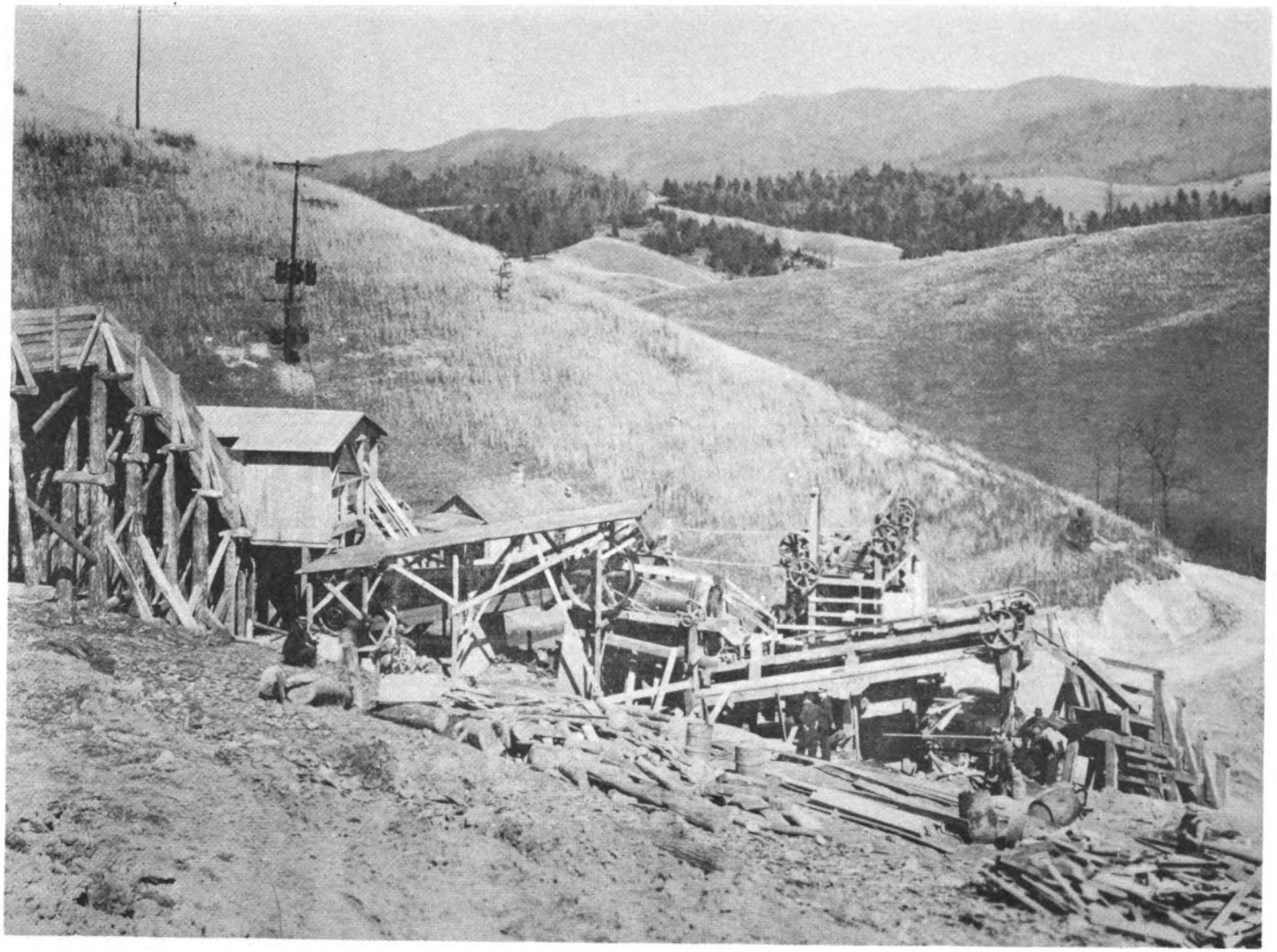

Figure 15.- East Tennessee Manganese Co.; washing and concentrating plant (looking east).

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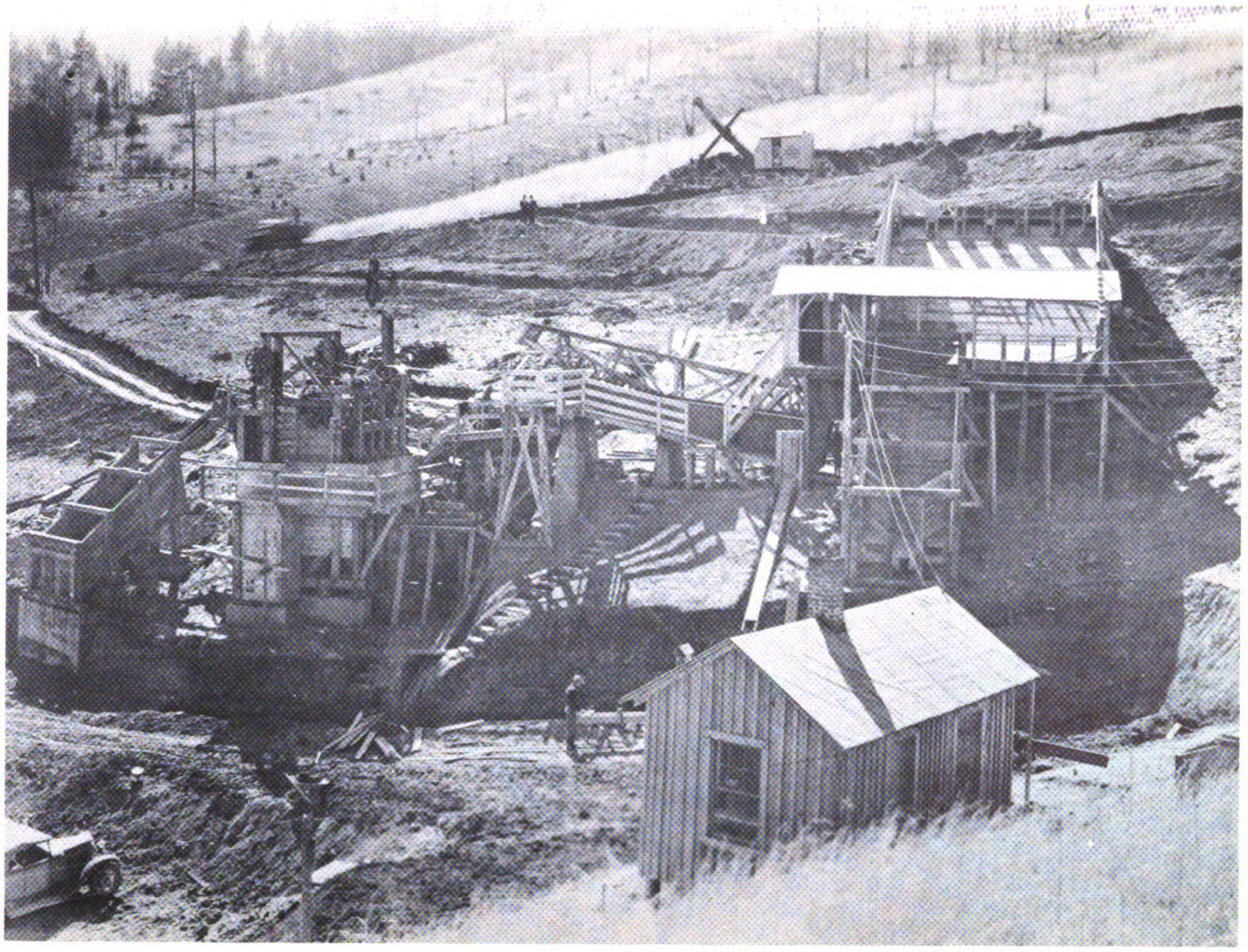

Figure 16.- East Tennessee Manganese Co.; washing and concentrating plant (looking west).

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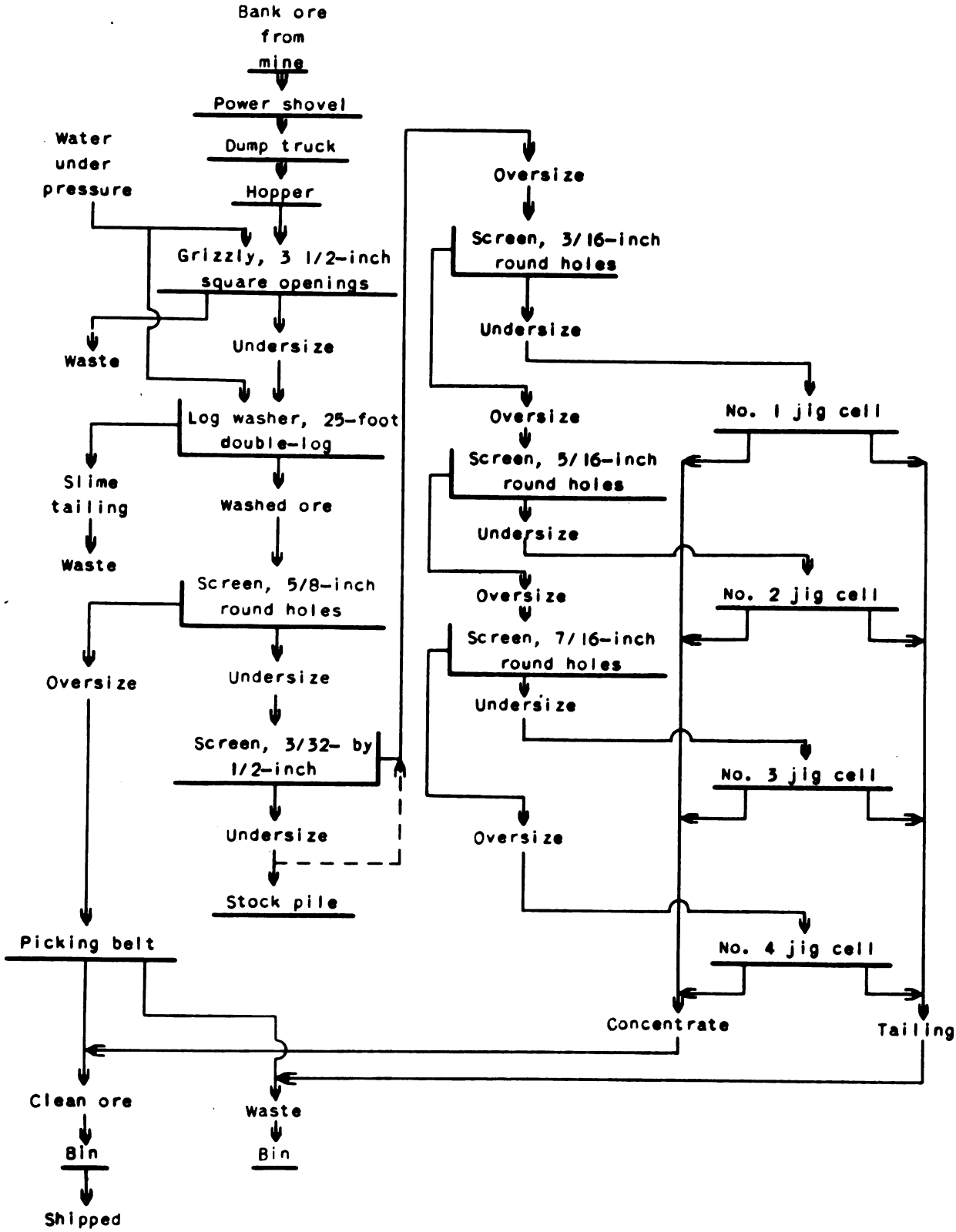

Figure 17.- East Tennessee Manganese Co., flow sheet of washing and concentrating plant.

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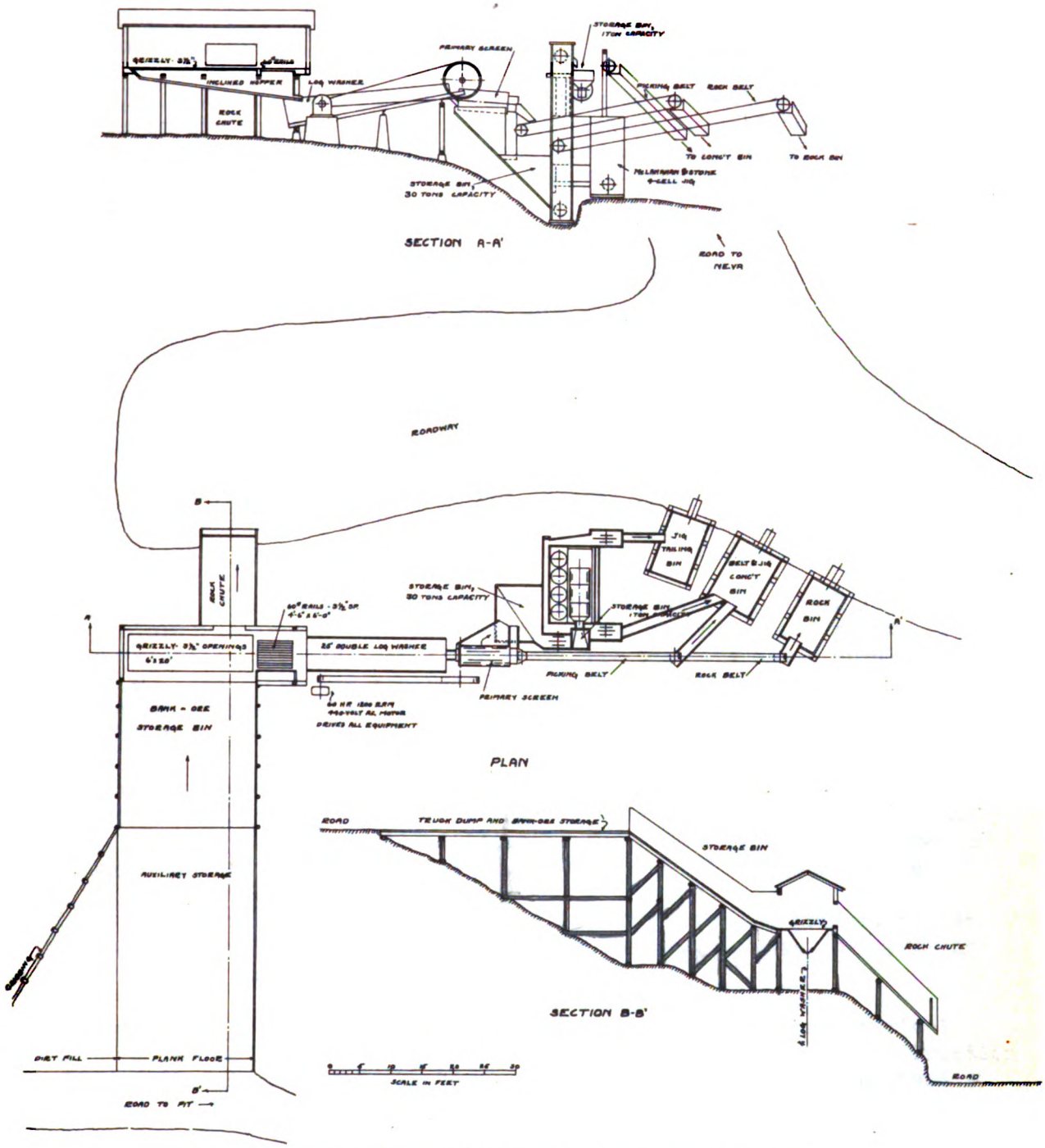

Figure 18.—East Tennessee Manganese Co. washing and concentrating plant.

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Storage Bin. - On account of the topography the arrangement of the bank-ore storage bin differed from that at the Embree operation. Ore was dumped directly into the bin and stored to a depth of several feet on the flat platform at the top of the bin. By this means one shift of mining furnished ore for operating the plant 24 hours. The bulldozer was used to push this ore into the inclined bin as needed.

Grizzly. - The construction of the grizzly was essentially the same as that at the Embree washing plant. It was 20 feet long by 7 feet wide, which gave about 40 percent of the horizontal screen area used at Embree. The screening surface was heavy screen wire with 5/8-inch rods spaced with a clear opening of 3 1/2 inches.

At the end of the grizzly toward the log washer was a section 6 feet long by 4 feet 6 inches wide, which was made of 60-pound rails set upside down with a 3-1/2 inch clear opening between them.

Water under a pressure of 100 pounds per square inch at the nozzle of a hose was used to sluice the feed down to the grizzly. An inclined hopper below the grizzly, constructed like that at the Embree washing plant, carried the undersize ore and water to the log washer.

Only coarse waste was separated and removed from the grizzly to the waste-rock bin immediately adjacent. (See fig. 13.) All ore was sledged on the rail section to pass the openings. Two men were used on the grizzly.

Log Washer. - A McLanahan & Stone 25-foot, double-log, steel log washer was used. This washer was identical with the one at the Embree plant. It was set at a slope of 2-1/2 inches per foot, and the logs had a speed of 19 1/2 r.p.m. The slope was steeper than that of the Embree washer and the speed somewhat greater. The feed entered the log-washer box on its center line about 2 feet from the lower end.

The log-washer concentrate was sprayed with clear water along the final 8 feet of the logs. Spraying did not break up the clay balls entirely, and plans were being made to install additional strong jets of water directed at a flat angle against the forward and upward movement of the concentrate.

The log-washer concentrate discharged directly into the primary screen. The tailing was carried by a wood flume under the road down to the upper of two tailing ponds, as shown in figure 12.

Primary Screen. - The primary screen was a double-shell, cylindrical screen set at an inclination of 3/4 inch per foot. It was mounted on friction rollers at each end and driven by bevel gears at the front end at a speed of about 20 r.p.m.

The inner shell of the primary screen was 31 inches in diameter and 10 feet 6 inches in length. The first 8 feet was covered with perforated plate which had 5/32- by 1-inch slotted openings. The last 3 feet had 5/8-inch square holes.

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The outer shell of the screen was 42 inches in diameter and 7 feet in length. It was covered with perforated plate having slotted holes 3/32- by 1/2-inch.

The oversize of the 5/8-inch screen discharged directly to the picking belt. The original plan was that the fine material passing the 3/32- by 1/2-inch slotted openings of the outer shell should be stock-piled until some satisfactory treatment could be developed for it. Temporarily it was being diverted into the storage hopper, with the material passing the 5/8-inch screen that was coarser than 3/32-inch. Consequently, everything finer than 5/8-inch was jigged.

Jig-feed Storage Bin. - All material passing the 5/8-inch screen dropped into a bin or hopper having a capacity of about 30 tons. From the bottom of this storage hopper it discharged through an adjustable gate to the boot of a bucket elevator. This elevated it to a small surge bin with a capacity of about 1 ton, above the feed end of the secondary screen over the jig. An adjustable gate controlled the rate of flow to the secondary screen. The adjustable gates of both bins were operated through levers by a man stationed at the upper surge bin. By means of this storage of jig feed, the jig could treat in 8 hours the product from the washer for 24 hours.

Secondary Screen. - The secondary screen was in the same position with respect to the jig and the same size (42 inches in diameter by 8 feet long) as the one at the Embree plant, however, instead of having two sections of screen of different sizes, as at the Embree plant, it had three sections. The screen made three undersize products and one oversize product, which were fed separately to the four cells of the jig.

The first 3 feet of the screen was plate perforated with 3/16-inch round holes. The next 2 1/2 feet had 5/16-inch holes, and the last 2 1/2 feet had 7/16-inch round holes. The undersize products were fed separately to the first three cells of the jig, and the oversize of the 7/16-inch screen was fed to No. 4 cell.

Jigging. - A McLanahan & Stone 4-cell jig was used (fig. 19). This jig was identical with that used at the Embree operation; however, it was operated in a somewhat different manner.

The sizes of material fed to the several cells were:

Jig cell No.:	Perforated-plate screen, diameter of round holes, 1/16 inch
1	Minus 3 and plus 0
2	Minus 5 and plus 3
3	Minus 7 and plus 5
4	Minus 10 and plus 7

The sizes of openings in the jig-bed screens were:

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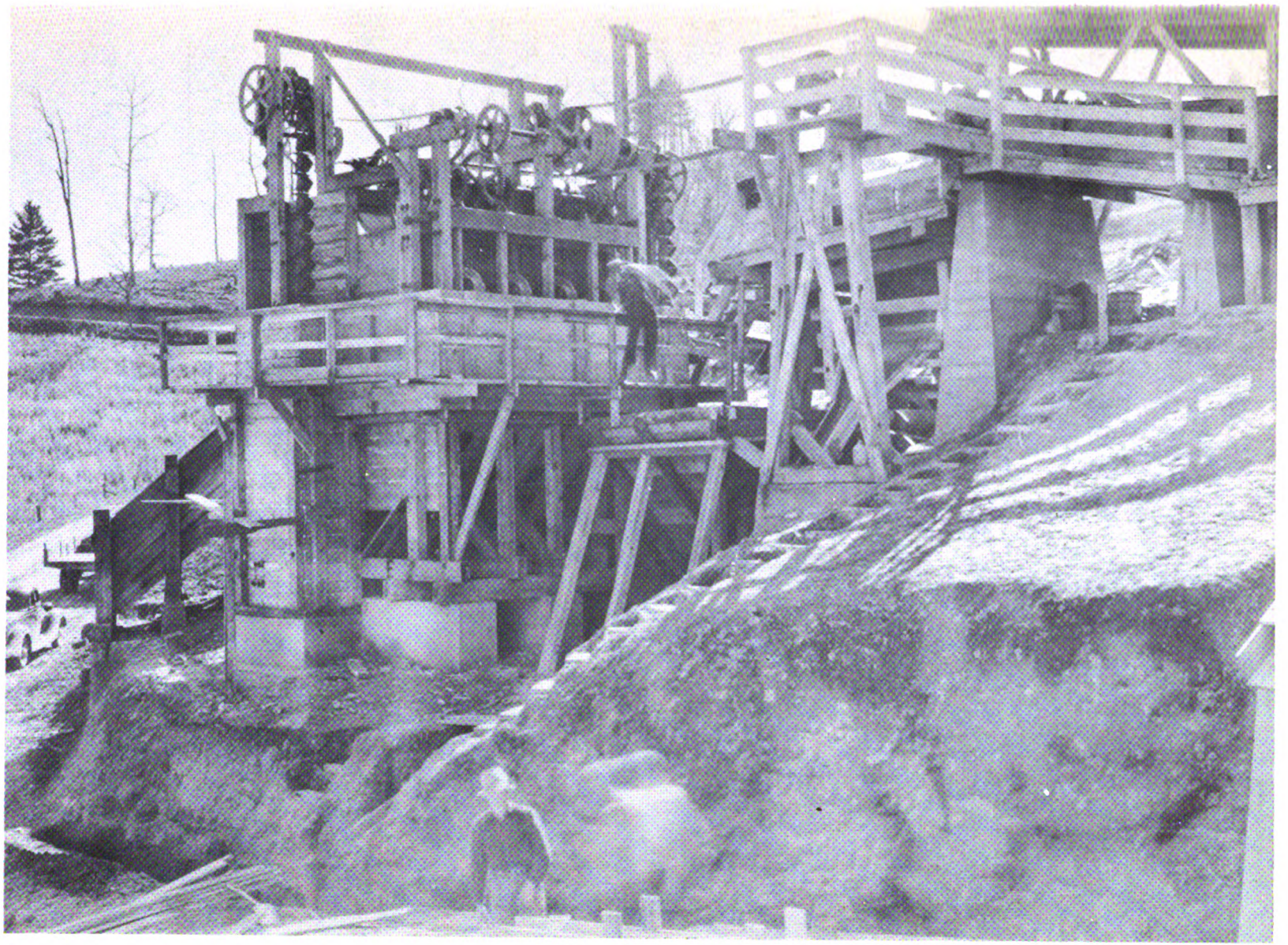

Figure 19.- East Tennessee Manganese Co.; McLanahan & Stone jig.

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Jig-cell No.:	Perforated plate screen
1	20-mesh (monel metal)
2	3/32- by 1/2-inch slotted holes
3	1/4-inch round holes
4	5/16-inch round holes

The eccentric shaft of the jig had a speed of 83 r.p.m., and the lengths of stroke used on the several cells were as follows: No. 1, 1 3/4 inches; No. 2, 3 inches; No. 3, 3 1/4 inches; and No. 4, 3 1/2 inches. The length of stroke was adjusted as the character of the feed changed.

Hand Picking. - Only one picking belt was used. This belt was 16 inches wide by 25 feet long between centers of the head and tail shafts. It sloped 12° and traveled about 30 feet per minute. The oversize of the 5/8-inch section of the primary screen dropped on the belt near the tail or lower end. Jig concentrate was discharged from the bucket elevator directly to a storage bin.

Six or more men picked waste rock from the belt and threw it into chutes, which delivered it to a belt conveyor immediately below the picking belt. This conveyor belt paralleled the picking belt but extended beyond it so that the waste rock was discharged into a rock bin whence it was hauled away as required.

Some high-grade pyrolusite was picked off to be shipped as chemical ore to Kingsport. Mud balls, which came through the washer, were thrown into nail kegs and periodically fed again through the washer.

Labor. - The tentative operating crew at the treatment plant for each shift follows: One foreman (day shift only), two grizzly men, one log-washer operator (acts as foreman on afternoon and night shifts), six men on the picking belt (maximum), one gate operator at storage bins, and two jig men.

As mentioned, the bulldozer pushed bank ore into the storage pocket during two shifts.

Water Supply

The washing and concentrating plant required about 250 gallons of water per minute, which was pumped through about 2,150 feet of new 4-inch pipe. The water was raised 200 feet vertically from the pumping plant on Mill Creek, as shown in figure 12.

The pump was a 4-inch Fairbanks-Morse built-in pump driven by a 50-horsepower, 220-volt motor.

Power

All equipment in the washing and concentrating plant was driven by flat belts, from pulleys on countershafts, by a 60-horsepower, 220-volt, 3-phase, 60-cycle, 1,200-r.p.m. motor.

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With the 50-horsepower motor on the main-water-supply pump, the total connected load was 110 horsepower. No figures were available on actual power consumption. Power was purchased from the East Tennessee Light & Power Co.

Wage Scale

A 42-hour week was observed on the operation. The following wage rates were paid for the several functions:

Classification:	Cents per hour
Power-shovel operator	95
Bulldozer operator	40
Truck foreman	40
Truck driver	35
Washing-and-concentrating-plant foreman	50
Log-washer operator	40
Grizzly man	30
Picking-belt man	30
Gate tender	30
Jigman	30

Haulage of Concentrate to Shipping Point. - Finished concentrate for shipment to Birmingham will be hauled in company dump trucks to cars spotted on a siding of the Southern Railway at Neva, about 1.9 miles from the concentrating plant. Chemical ore will be trucked direct to Kingsport, either in company trucks or under contract.

Freight Rate. - The N. O. I. B. N.[27] rate from Neva to Birmingham was $3.08 per long ton for concentrate containing less than 43 percent manganese. A petition has been made for a special rate to cover actual shipments.

Cost of Plant and Equipment

The washing and concentrating plant was constructed during the winter of 1939-40, which was unusually severe in that section. As a result, the construction costs were somewhat higher than normal.

New equipment was purchased and installed for all parts of the operation. Summarized plant and equipment costs follow:

27/ Not otherwise indicated by name.

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Plant and equipment costs, East Tennessee Manganese Co.

	Weight pounds	Price f.o.b. Pa.	Delivered cost
1 Northwest, 3/4-cubic yards, gasoline-driven power shovel..	.....	.....	$ 8,000
1 bulldozer.....	.....	.....	5,500
3 dump trucks, 2 1/2-cubic yard bodies, total.....	.....	.....	4,200
One 8-inch by 25-foot light-duty type, McLanahan & Stone, all-steel log washer.....	29,000	$ 4,132	.....
1 double-shell sand screen.....	1/ 1,500	760	.....
One 16-inch by 30-foot picking belt, complete.....	1/ 1,500	500	.....
1 four-cell, McLanahan & Stone jig, complete with timber....	44,000	4,500	.....
Subtotal.....	76,000	9,892	.....
Freight on shipments from Pennsylvania, estimated at $2.00 per hundredweight.....	.....	.....	1,520
Total delivered price for shipments from Pennsylvania.....	.....	.....	11,412
1 water-supply pump, motor, and starter.....	.....	.....	740
1 60-horsepower motor and starter	.....	.....	735
Switches and wiring.....	.....	.....	213
Subtotal, equipment.....	.....	.....	$30,100
Subtotal, miscellaneous2/.....	.....	.....	16,400
Total.....	.....	.....	46,500

1/ Estimated.

2/ Haulage of equipment to property; grading and foundations; installation of equipment; installation of wiring and piping, including 2,150 feet of 4-inch pipe from pump; construction of ore-storage pocket, grizzly, launders, working platforms, roof sections, and bins; construction of roads and tailing ponds.

To the foregoing items must be added the cost of engineering services, analytical work, supervision of construction, and $1,000 for drilling 800 feet of exploratory churn-drill holes at $1.25 per foot.

In round figures, an expenditure of $60,000 was necessary to begin an operation capable of producing 10,000 tons of concentrate a year.

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COMPARISON OF NORTHEAST TENNESSEE MANGANESE-ORE TREATMENT PRACTICE WITH THAT OF OTHER APPALACHIAN DISTRICTS

Separation of Coarse Material on Grizzlies

Grizzlies in Appalachian manganese-ore treatment plants are usually flat and vary greatly in area. Crane[28] states that in the Cartersville district the usual size is 3 by 5 feet, or 15 square feet, which appears to agree with present practice in that district. This size is very small compared with that of more than 340 square feet at the Embree Iron Co. and another of 120 square feet at the East Tennessee Manganese Co.

At most plants where smaller grizzlies are used the grizzlies are made of rails of various weight. These rails are placed upside down, 3 to 5 inches apart. The two northeastern Tennessee plants described in this paper use heavy screen wire with square openings of 3 1/2 inches between 5/8-inch rods. Both plants use smaller sections, made of rails, on which coarse lumps of ore are sledged.

In usual practice water under pressure from the nozzle of a hose is used to sluice bank ore to the grizzly, to aid in passing the finer material through the grizzly to the log washer, to break up balls of clay, and to clean the coarse lumps of waste and ore. The grizzlies are placed so that the undersize either drops directly into the log-washer box or collects in an inclined hopper which leads to the desired feed point of the log washer.

Except for the two plants in northeastern Tennessee, all plants visited had no storage bins ahead of the grizzlies, and trucks dumped ore directly upon the grizzlies.

Ordinarily coarse lumps of waste rock are removed from the grizzly by hand, and all remaining material is sledged to pass the openings. At some plants coarse lumps of high-grade ore also are removed and either shipped as selected ore for chemical use or combined with other concentrates before shipment.

Log-Washer Practice

Early Log-washer Construction. - Log washers have been used for many years in the Appalachian region for separating iron and manganese ores from the clay with which they are associated. As log washers at Appalachian manganese-ore deposits range from rather crude equipment, typical of that used many years ago, to the most-modern, factory-built, all-steel machines, a discussion of the development of log-washer construction may be of interest.

28/ Hull, J. P. D., LaForge, L., and Crane, W. R., Manganese Deposits of Georgia: Georgia Geol. Survey Bull. 35, 1919, p. 261.

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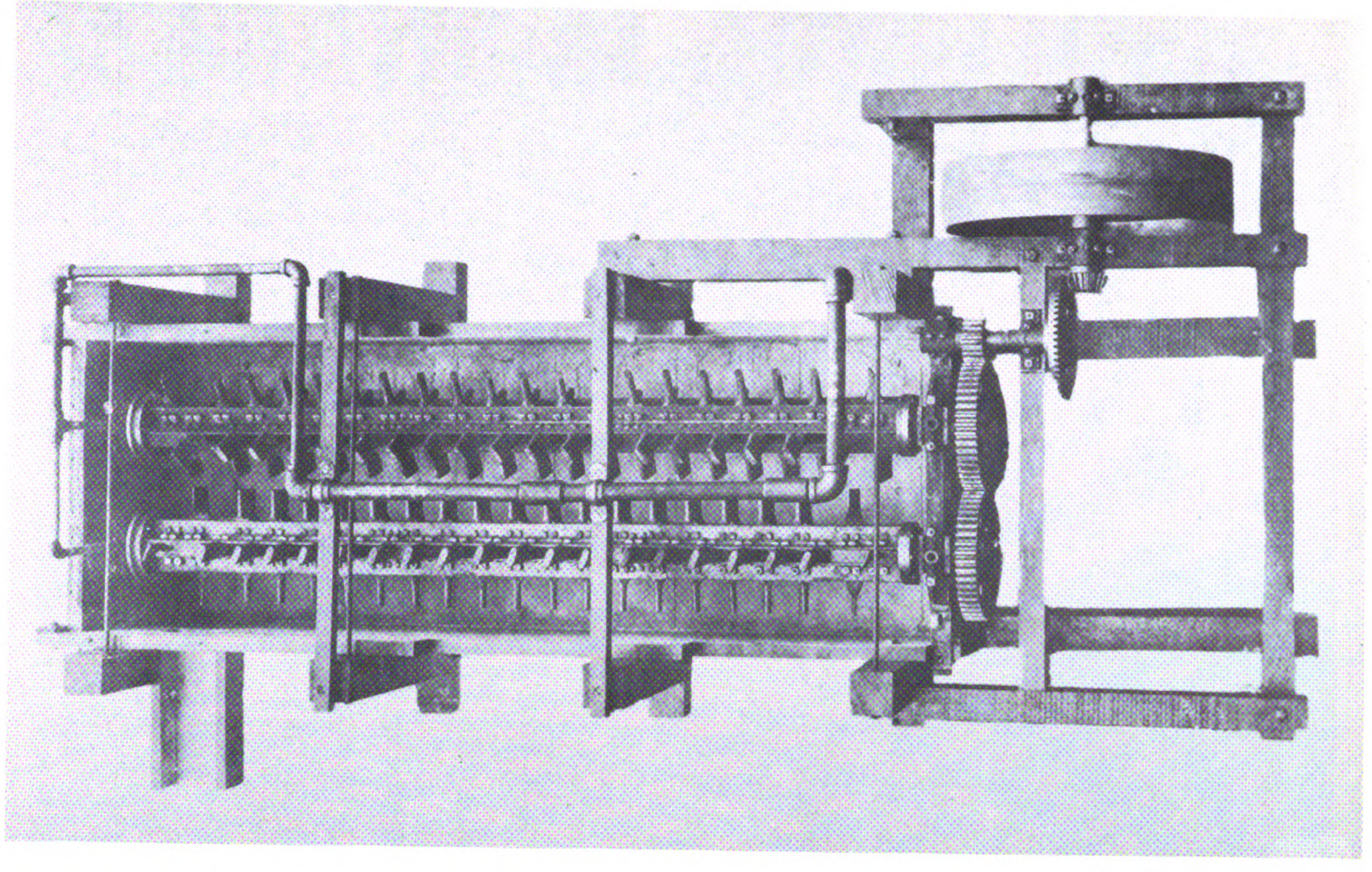

Figure 20.- Early form of steel log construction with chilled iron paddles.

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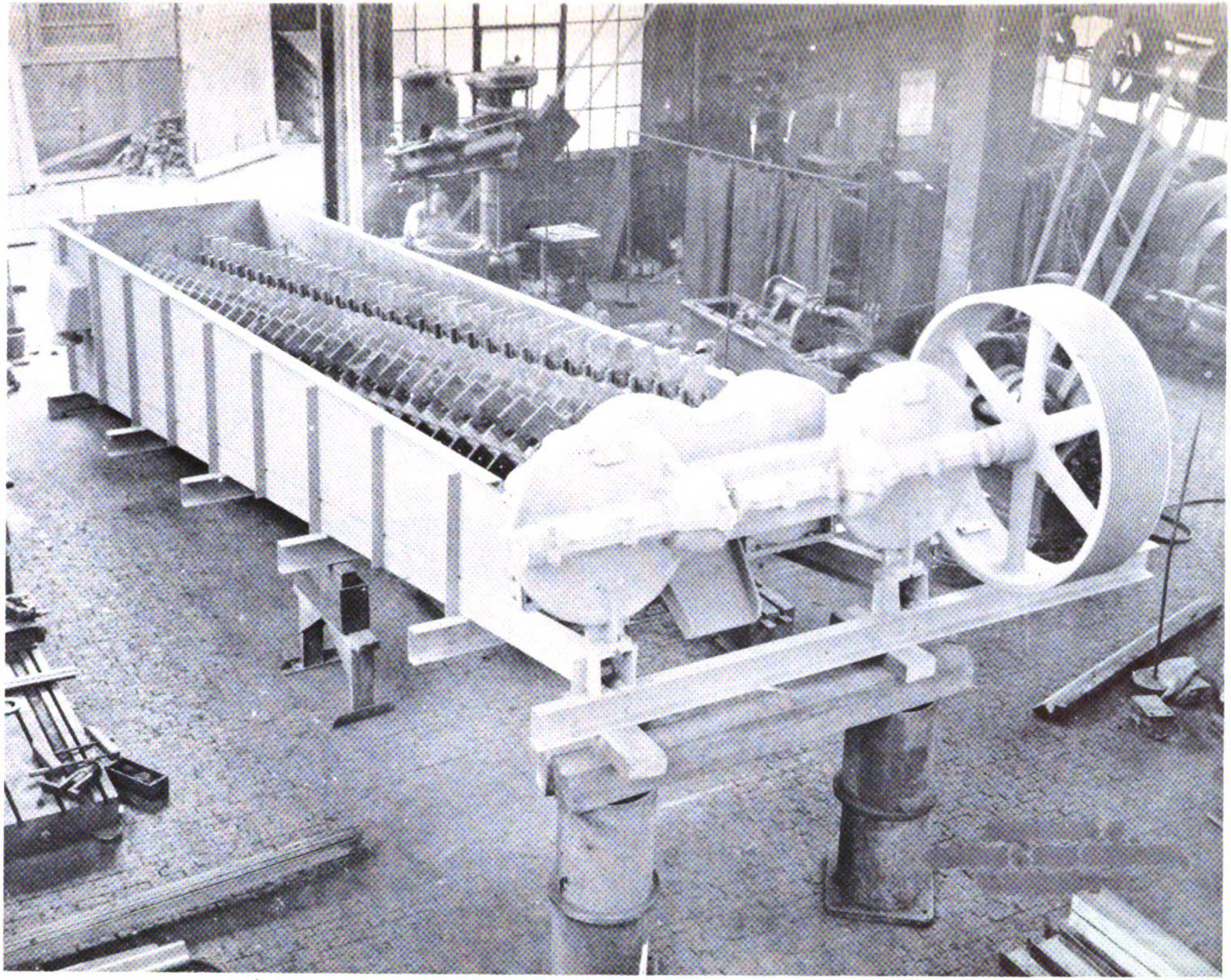

Figure 21.- General view of discharge end of modern 25-foot log washer with adjustable discharge spout.

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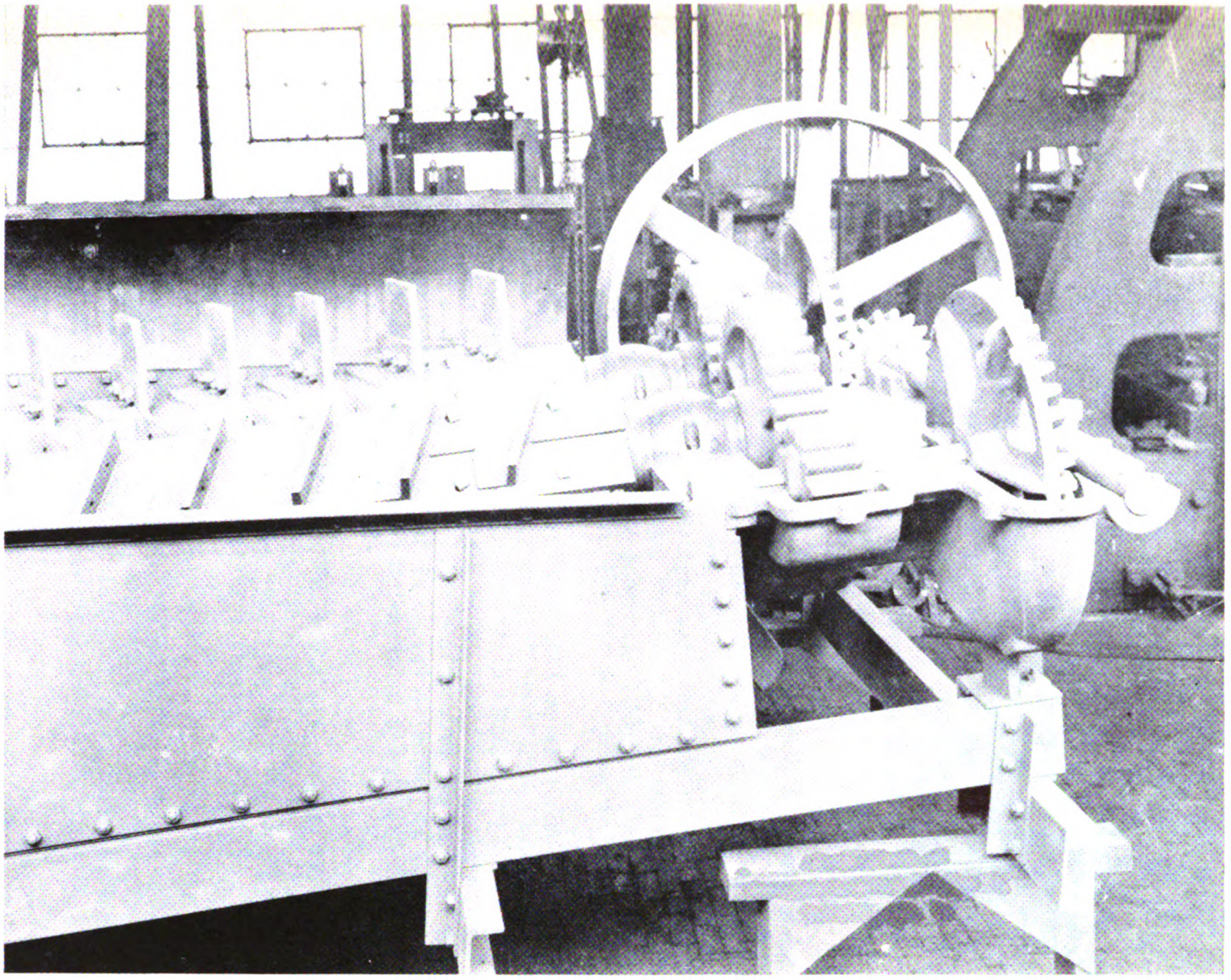

Figure 22.—Gear drive of 25-foot steel log washer with top of gear case removed.

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The primary function of a log washer is to mix and agitate the ore and clay with water so that the clay will be broken up and held in suspension in the water while the lumps of ore are freed. The secondary function is to separate the particles of clean ore from the suspended particles of clay.

The first function is accomplished in a box, partly filled with water, in which one or two shafts with attached paddles are rotated. To separate the muddy water from the ore the box is set at an inclination and provided with an overflow at the rear or lower end through which the clay in suspension passes. The paddles are set at an angle to the shafts, so that they act as an interrupted screw conveyor and transport the ore forward and up the slope of the box. Before the lump ore is discharged at the upper end of the box it emerges from the pool of muddy water and is sprayed with clean water under pressure. The action consists of breaking lumps of clay and stirring, mixing, lifting, and forcing the ore forward up the sloping bottom against a downward-flowing stream of clear water.

The earliest log washers were very crude. Ordinarily a single shaft was used. These were made of logs, hence the name "log washer." The early paddles were riven, hardwood shakes, mortised and driven into the log at the desired angle. Sometimes heavy spikes were used as paddles. Local foundries began to furnish cast-iron paddles, bearings, and other iron work. As double logs became popular cast-iron gears became necessary. The boxes invariably were made of heavy plank. There were no generally accepted standards, and each operator built his own log washer on the job according to his own ideas.

Logs were also made of cast iron, with flanges on each end similar to pipe. These logs were intended as an improvement over wooden ones, but no satisfactory method was found of bolting paddles to them. Later some manufacturers began to build logs of four-angle irons, to which chilled iron paddles were bolted. Frequently these logs replaced wood logs in the earlier log washers. The construction of logs of this type is shown in figure 20, reproduced from a photograph furnished by McLanahan & Stone Corporation of Hollidaysburg, Pa.

Many variations of home-made log washers still are used on Appalachian manganese ores, although manufacturers have developed complete, all-steel units, which are extremely rugged and free from trouble. These units may be somewhat higher in first cost, but they pay for themselves by requiring fewer repairs and less lost time.

Modern Log-washer Construction. - Before 1930 large tonnages of low-grade iron ore in the Lake Superior iron region were treated in log washers, and factory-built machines with steel logs and integral steel boxes increased in popularity. The machines as developed by several manufacturers were strengthened and made more rugged.

All-steel log washers of this type are used in the two northeastern Tennessee manganese-ore treatment plants described in this paper. The machines in both plants are identical, as shown in figures 21 and 22. They are

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designated as 8-inch by 25-foot, light-duty, double-log washers. Each log is made of two 8- by 8- by 3/4-inch angles welded from end to end to form a box 8 inches square in cross section. Paddle tips are bolted to bases, which in turn are welded to the logs. The paddle tips are reversible and interchangeable. They are made of an alloy steel that resists abrasion. (See fig. 23.)

At the lower end the logs are supported in a hexagonal steel gudgeon which drives a removable thimble. This thimble operates in a water-lubricated step bearing. The logs are driven, at the head end, through cut-steel gears running in oil, within a tightly closed housing.

These washers weigh approximately 29,000 pounds and are now quoted at about $4,135 complete, f.o.b. factory. One may also obtain everything complete, except the steel box, at about $3,475 f.o.b. the same point for those who desire to build wood boxes at their plants. It is doubtful whether a properly constructed wood box could be built for less than the $660 difference in price, and such a box would not be as substantial or last as long as one of steel.

Operation

Length. - Although the length of present log washers ranges from 20 to 36 feet, 25- and 30-foot log washers are common and are almost standard.

The length of a log washer has no bearing upon the capacity of the machine but has an important bearing upon the amount of scrubbing and cleaning the washer will accomplish. Where unusually tough clay must be broken or soft sandy rock abraded two log washers sometimes are placed in series.

The length of a log washer and the slope of the box are closely related. A longer log can be set at a flatter slope and give the proper submergence of the logs at the rear end without discharging too much water with the concentrate.

Slope. - Crane[29/] states that in 1918 the slope of log washers in plants treating manganese ore ranged from 1 to 1 1/2 inches per foot, being "more or less arbitrarily chosen." He states further that if the ore is easy to clean the slope of the washer may be flatter, whereas if it is difficult to clean the slope may be steeper.

At the Embree washing plant the slope of the log washer is 2 inches per foot, and at the East Tennessee Manganese Co. it is 2 1/2 inches per foot.

Speed. - The usual speed of the logs ranges from 16 to 26 r.p.m. A speed of 18 r.p.m. is used at the Embree plant and a speed of 19.5 r.p.m. at the East Tennessee Manganese Co. plant. Other factors being equal, the higher the speed of the logs the larger the capacity of the machine.

29/ Hall, J. P. D., LaForge, L., and Crane, W. R., Manganese Deposits of Georgia: Georgia Geol. Survey Bull. 35, 1919, p. 274.

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SIZE	A	C	1½" IN 12" INCLINATION B	1½" IN 12" INCLINATION D	1½" IN 12" INCLINATION E	2" IN 12" INCLINATION B	2" IN 12" INCLINATION D	2" IN 12" INCLINATION E
20'	20'-5½"	3 spaces	5'-10⅛"	2'-9⅜"	4'-9⅛"	5'-9¾"	3'-8⅜"	4'-8¾"
25'	25'-5½"	3 spaces	7'-6⅛"	3'-3⅜"	4'-9⅛"	7'-5 9/16"	4'-6⅜"	4'-8¾"
30'	30'-5½"	4 spaces	6'-10⅝"	4'-0⅜"	4'-9⅛"	6'-10⅛"	5'-4¼"	4'-8¾"
35'	35'-5½"	4 spaces	8'-1⅝"	4'-7⅞"	4'-9⅛"	8'-1"	6'-2⅛"	4'-8¾"

No.	Req'd.	Name
1	2	Log gudgeon with hex. ends
2	2	Log gudgeon with 7" dia. neck
3	1	Front plate and gear case
4	1	Gear-case cover
5	1	Back plate
6	2	Chilled thimble
7	2	Hard-iron box
8	1	Drain-hole cover plate
9	2	Step-bearing cover plate
10	1	Discharge spout
11	1	Discharge-spout gate
12	2	7" ball and socket bearing
13	1	Overflow spout
14	1	Overflow-spout adjustable gate
15	2	Overflow-spout adjustable gate guide
16	1	Overflow-spout adjustable gate handwheel
17	1	Overflow-spout adjustable gate bracket
18	2	Overflow-spout adjustable gate bracket cover
19	216	Paddles
20	2	Manganese screw
21	2	Spur wheel
22	2	Spur pinion
23	2	Bevel wheel
24	2	Bevel pinion
25	2	Bronze bearings
26	2	Keeper
27	2	Steel log
28	1	Line shaft
29	2	Countershaft
30	1	Adjusting rod

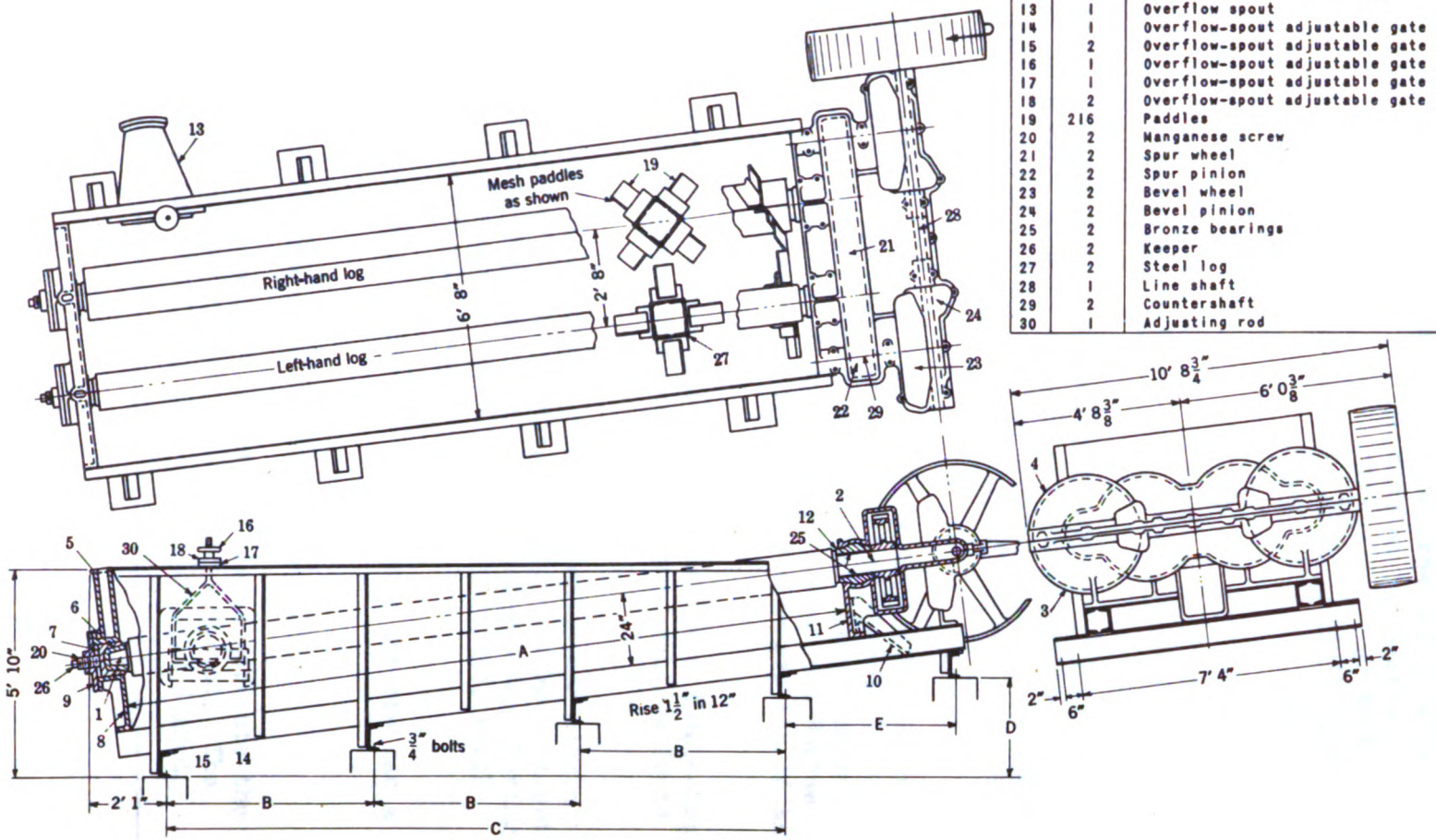

Figure 23.- General arrangement and list of parts for steel log washer.

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Paddles. - The following data indicate the development of paddle design by the McLanahan & Stone Corporation.

	Chilled-iron paddles on original wood logs	Chilled-iron paddles on first steel logs	Alloy-steel paddles on present steel logs
Number of paddles[1].....	78	98	108
Diameter of paddle, tip to tip.....inches	39	35	36
Size of paddles.....do..	5 by 8 1/2	5 by 9	7 by 10 1/2

1/ Number of paddles used on a 25-foot log.

The chilled-iron paddles used on wood logs are typical of log washers built in 1889. Steel logs were patented in 1890 and became popular early in the present century. The current paddle and log construction was developed only a few years ago. Paddles are set at an angle of 67° to 68° with the axis of the logs.

Water Consumption. - Crane[30] states that in Cartersville 50 gallons of water per minute is considered sufficient for a single log whereas double logs "require fully 75 gallons of water per minute." This relatively small amount compares with 500 or 600 gallons of water per minute at the Embree plant. Thus the quantity of water may range from 1 to 8 tons per ton of bank ore fed to the log washer.

Power Consumption. - Crane[31] states that in Cartersville a double-log washer produces 40 to 50 tons of washed ore in 10 hours and requires 20 to 25 horsepower to drive it.

At the Embree washing plant the 25-foot double-log washer and picking belt in 1939 required an average of 19 horsepower, as indicated by a recording meter. The washer alone probably required 17 1/2 to 18 horsepower. During that year bank ore was fed at an average rate of 18 tons per hour, which yielded 3 tons of washed ore or concentrate.

As a rule less power is required to drive a washer when the ore has a large proportion of clay.

Primary Screening of Log-washer Concentrate

Virtually all Appalachian manganese-ore treatment plants separate the coarse lumps of the log-washer concentrate from the finer material. The coarse material is handpicked, and the finer material usually is jigged.

30/ See footnote 29.
31/ See footnote 29.

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Size of Screen Openings. - This size depends somewhat on whether jigs are used. If they are not, screens with 1/4- to 1/2-inch openings are used. The oversize then goes to the picking belt and the undersize is discarded, stock-piled to be available for later treatment, or sold as a low-grade product.

When jigs follow the log washers the size of screen opening in the primary screen depends largely on the method of jigging. At the two plants in northeastern Tennessee described in this paper, 3/4- and 5/8-inch openings are used. At one plant in Cartersville, 1-inch openings are used. These sizes represent about the usual range.

Type of Screen Used. - Cylindrical trommels of various sizes are used in most Appalachian plants. They are either mounted on shafts or supported on rollers and are driven by bevel gearing. Usually these screens are set at an inclination of 3° to 15°, and revolve at 10 to 20 r.p.m., depending on the length and diameter of the screen and the desired capacity.

At one plant in Cartersville a vibrating screen is used. As the tonnages handled at this plant are comparatively small, there does not seem to be any particular advantage in such a screen.

Hand-picking Practice

Picking Belts. - Crane[32/] states that the common sizes of picking belts in Cartersville in 1918 were 30 feet long by 18 inches wide and 50 feet long by 30 inches wide and that they traveled 50 to 60 feet per minute. The shorter, narrower belts seemed more in accord with present practice in that district.

In northeastern Tennessee belts are generally 30 feet long and either 16 or 18 inches wide. Longer belts are used in the Embree concentrating plant and have proved desirable. The speed of the belts in the two Tennessee plants is only about 30 feet per minute.

Virtually all belts slope toward the tail end to carry off wash water from the fine sprays that usually give the material a final cleaning. Some picking belts are set at much steeper slopes to elevate the material to a desired point.

Picking Practice. - Sometimes waste rock only is removed from picking belts. More often, some high-grade ore also is removed. Crane[33/] states that at a few plants, where there is more waste than ore, the ore is picked off and the waste allowed to discharge from the end of the belt. None of the Appalachian manganese-ore treatment plants visited by the author has adopted this practice.

32/ See footnote 29.
33/ See footnote 29.

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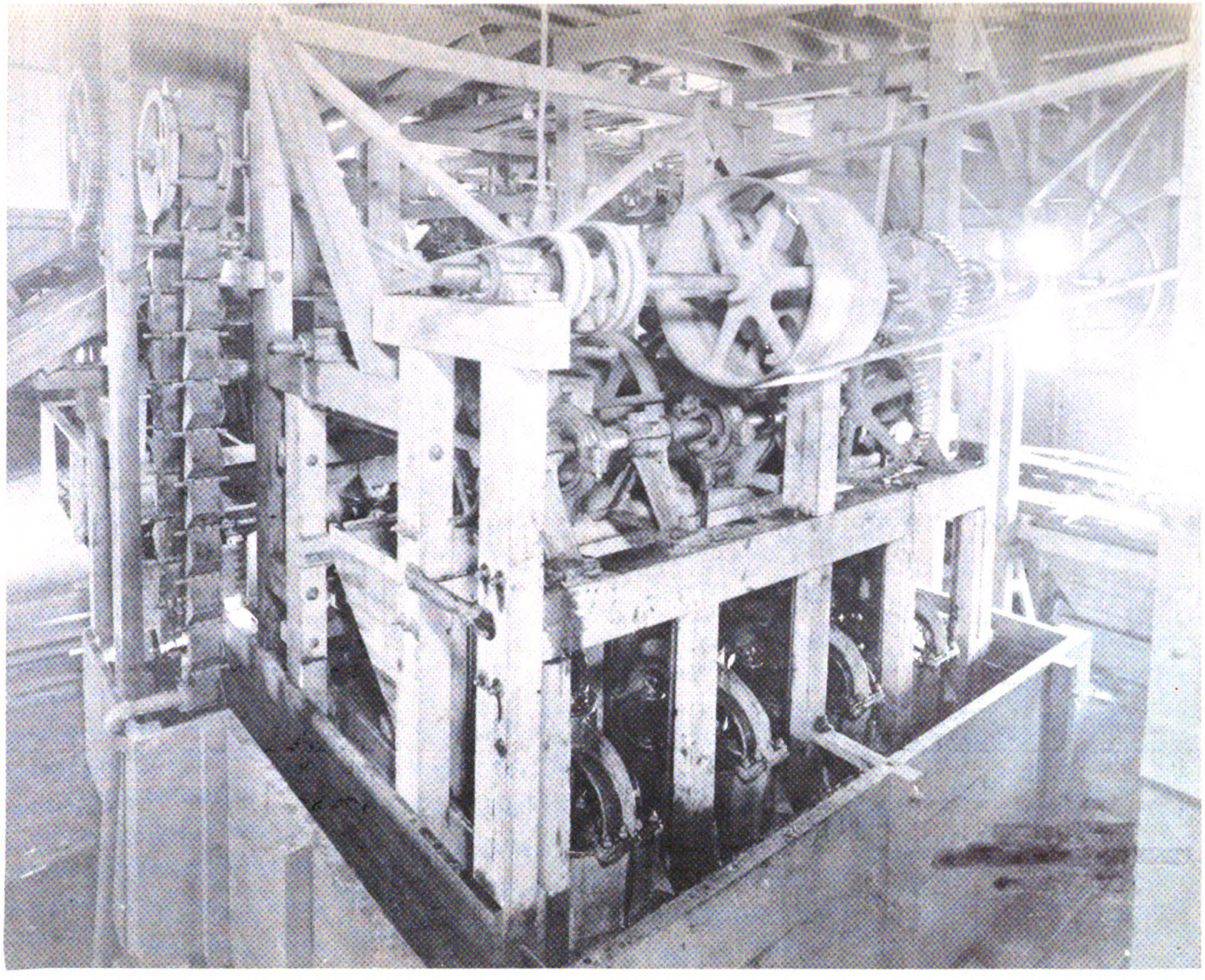

Figure 24.- Embree Iron Co.; rear view of four-cell McLanahan & Stone jig.

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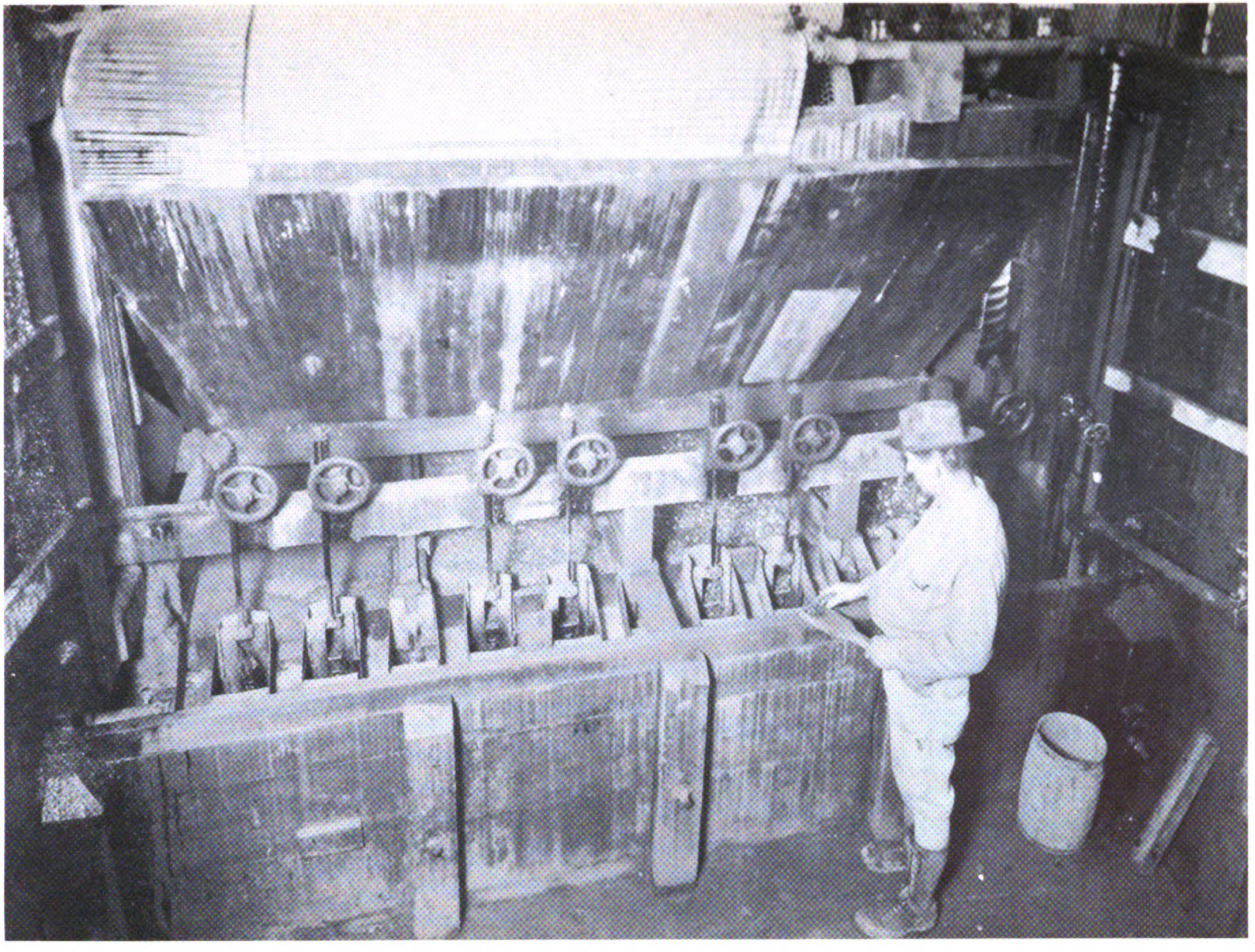

Figure 25.- Front view of four-cell McLanahan & Stone jig.

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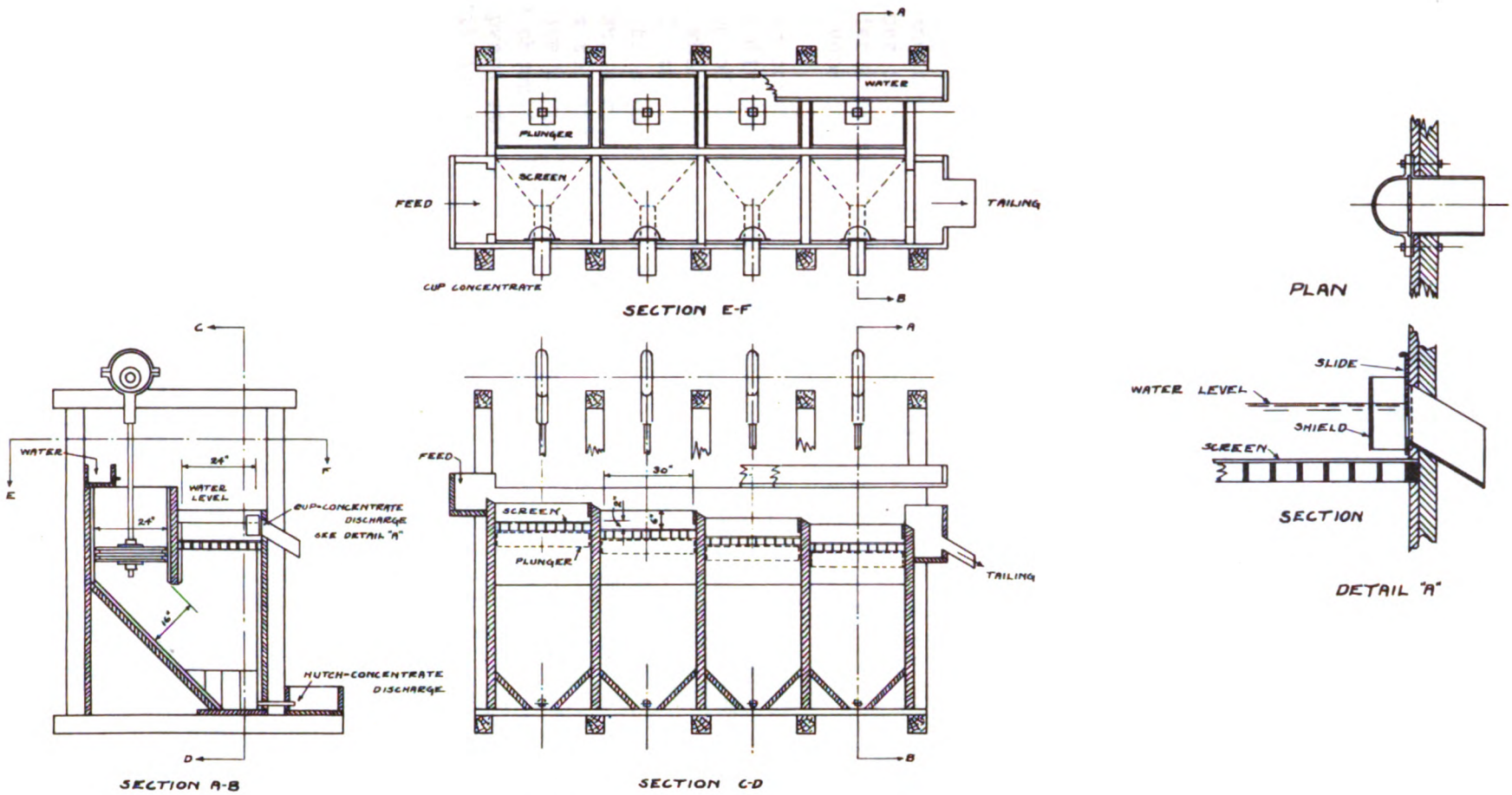

Figure 26.- Sections through Harz jig.

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Usually no further treatment is given the coarse material after hand picking; however, at one plant visited in Cartersville the ore remaining after the waste is picked from the belt is reduced in a jaw crusher and by rolls to the maximum size jigged and returned by a bucket elevator to the log washer. Another plant in Cartersville also was planning to adopt this practice.

The character of the particular ore would determine whether this practice would be beneficial. Additional waste undoubtedly would be removed by the second passage through the log washer, but an excess of fine material might be produced, which would complicate later treatment and make the final product objectionable for furnace use.

Jigging

Although jigs are not used universally in Appalachian manganese-ore treatment plants for cleaning log-washer concentrate, in most cases their use would be desirable.

In another section of this paper it was explained that jigs depend on differences in the specific gravity of the ore and gangue particles, that they treat moderately coarse particles, and that they utilize vertical currents of water to separate the particles of ore from the waste.

A jig consists essentially of a box with a V-shaped bottom filled with water and divided into two sections by a partition extending part way to the bottom of the box. (See figs. 24 and 25.) On one side of the box is a plunger, which moves up and down by means of an eccentric mounted on a drive shaft. On the other side a flat screen supports the particles of ore and waste to be separated, as shown in section A-B, figure 26. As the plunger moves down, a rising current of water is forced through the screen section and tends to lift all particles on the screen. The lighter particles of gangue move upward more readily than the heavier particles of ore. In the Harz jig shown in figure 26 the water is sucked downward through the screen on the upward stroke of the plunger thus accelerating the fall of the particles. By repetition of these upward and downward currents of water through the screen, the particles arrange themselves in layers with the lightest ones on top and the heaviest ones on the bottom next to the screen. The lighter particles of waste are floated off with the water over the discharge partition. The heavier particles of concentrate are removed by a device shown in Detail A, figure 26.

The two general practices in jigging follow:

1. Closely sized particles are treated in separate jigs or cells, and all separation is done on top of the jig screen, which has openings finer than the smallest particle.

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2. A mixed feed, finer than some limiting size, is treated on one jig or cell. Many of the particles of ore and gangue are finer than the openings of the jig screen. The heavy particles of ore, finer than the screen openings, fall through the screen into the hutch, whereas the small particles of gangue float off.

Both jigging practices are used in Appalachian manganese-ore treatment plants. The first, for jigging a closely sized feed, was adopted in the Northeastern Tennessee plants described in this paper, where McLanahan & Stone jigs are used. The second practice is used in Cartersville, where Harz jigs are employed. The construction and operation of these jigs are described below.

McLanahan & Stone Jig. - This jig was invented in the seventies and has been used widely on iron ores and to some extent on manganese ores. The jig has been improved from time to time since it was first invented and is now built in several sizes.

Figure 27 shows the essential features of construction of the jig. The plunger is made of cast iron and operates in a closely fitting cylinder. On the up stroke of the plunger, water flows into the jig box from the water-return launder through rubber valves. Later models have three valves instead of two. On the down stroke, these valves close and the water is forced rapidly up through the screen section. This action is followed by the slow, downward current of water through the screen on the upward stroke; thus the jig operates by pulsion currents alone.

The feed enters the jig-screen compartment along the partition separating it from the plunger compartment. All particles work their way across the jig to the opposite side, where the concentrate and tailing are discharged separately into inclined compartments which are filled with water to the same level as the jig-screen section. On recent models the hutch product is drawn off through a gate in the V-shaped bottom of the jig.

The particles of concentrate flow along the inclined bottom of this water-filled compartment into the boot of a bucket elevator, which also is filled with water to the same level as the jig-screen compartment. The buckets of the elevator are perforated so that the excess water drains off the particles of concentrate before they are discharged. An open trough extends from the concentrate elevator box along the end of the jig to the return-water trough, shown in section A-B, figure 27. On the opposite end of the jig a similar elevator drains, raises, and discharges the particles of tailing.

The arrangement of the concentrate and tailing discharges is shown in "Detail A," in figure 27. For each of the four jig cells, tailing flows around two concentrate discharge wells and through three spouts into the inclined chute to the tailing elevator. The concentrate flows through adjustable gates which can be raised or lowered by handwheels. These gates are also shown in figure 25.

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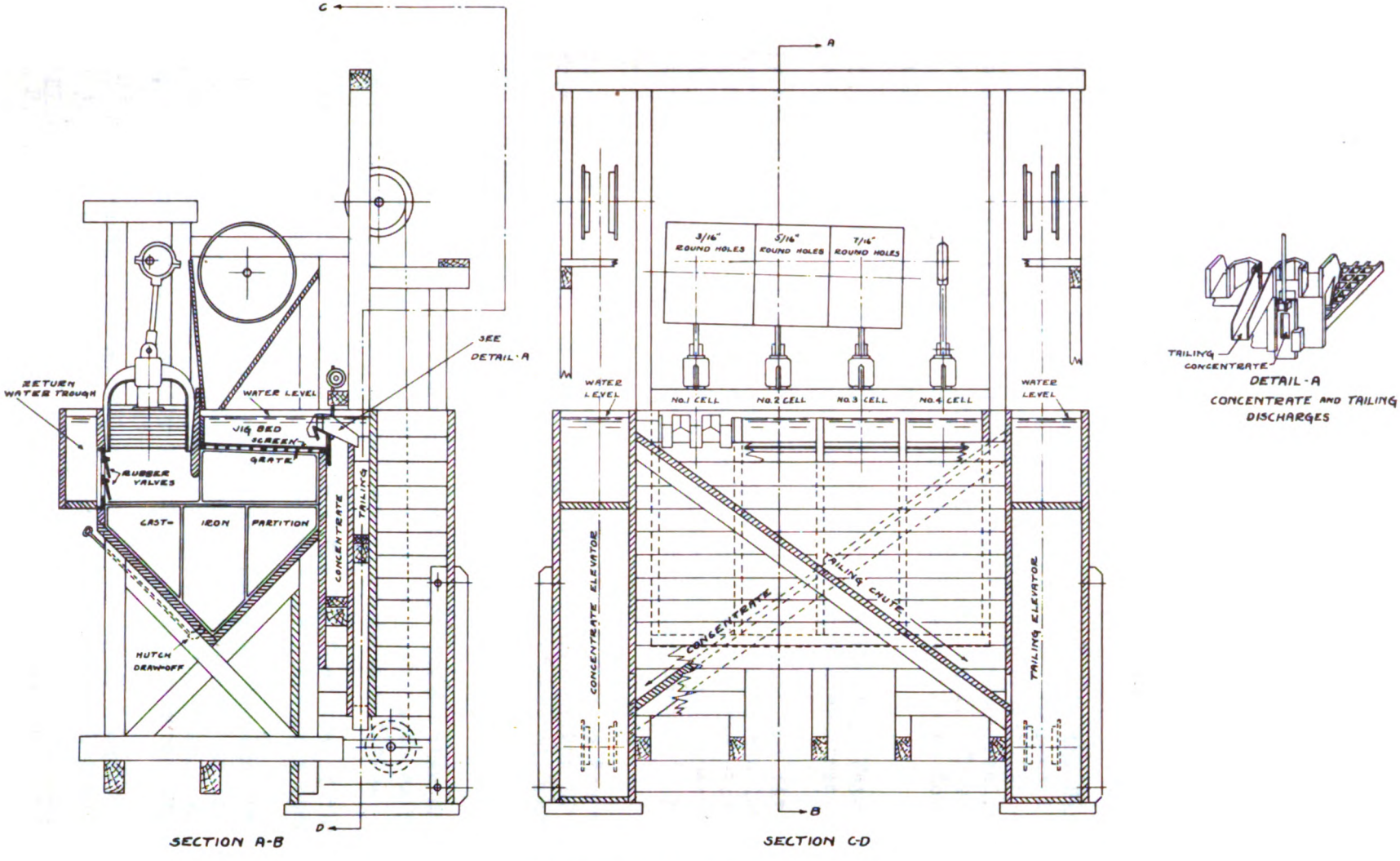

Figure 27.–Four-cell McLanahan & Stone jig.

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Usually each cell in a jig of this type is fed with a closely sized feed direct from a secondary cylindrical screen mounted above the cell. In each cell the jig screen is supported on cast-iron gratings. The openings in these jig screens are smaller than the smallest particle fed to that section.

The plunger for each cell is driven by an adjustable throw eccentric, so that the length of stroke can be changed. In general, the longest stroke of the plungers is used with the coarsest particles and the shortest stroke with the smallest-size material.

Harz Jig. - The Harz jig was developed many years ago in the Harz Mountains of Germany. Figure 26 shows the general construction of a four-cell jig of this type. The feed enters one end of the jig and flows lengthwise along all four compartments to the other end, where the tailing is discharged. Concentrate is removed through discharges at the side of each cell. These discharges are shown in "Detail A," figure 26. Some concentrate also passes down through the bed on the jig screen into the hutch.

Water flows off freely with both tailing and concentrate. Water to replace this loss is fed from a launder over the plunger compartments.

Usually the plungers are made of several layers of wood and fit closely in the compartment in which they operate. They are set below the level of the screen so that they will always be covered with water. The closer the plungers fit, the greater is the suction down through the jig screen on the up stroke of the plungers. A jig of this type therefore uses both pulsion and suction.

As a rule one jig with two to four compartments is used on the coarser material, from 1- to 1/2-inch. A second jig with the same number of compartments takes all material finer than 1/2-inch. At some plants all material below the size handled on the picking belt (usually minus 3/4-inch) goes to the first jig.

In jigging mixed feed the jig-screen openings are larger than many of the finer particles in the feed. A layer of heavy mineral, such as cast-iron balls, is placed on the jig screens or allowed to accumulate there.

This is termed a "filter bed" or simply a "bed". The size of the particles in this bed usually is several times that of the screen opening.

In theory, only the heavy, small particles pass down through the bed into the hutch, whereas the lighter ones of the same size float off as tailing. In practice, many fine gangue particles also pass into the hutch. Where this happens, the hutch product usually is retreated on a second jig.

Crane,[34] in discussing Cartersville practice in 1918, suggests the use of three jigs, as follows: (1). The coarse sizes to be treated on a rougher jig; (2) the fine, mixed sizes to be treated on a sand jig; and

[34] Hull, J. P. D., LaForge, L., and Crane, W. R., Manganese Deposits of Georgia: Georgia Geol. Survey Bull. 35, 1919, p. 277.

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(3) the hutch product from all cells of the rougher jig except the first cell, also from the last two or more cells of the sand jig, to be treated on a third, or cleaner, jig.

Rarely are more than two jigs of this type used in Appalachian manganese ore treatment practice.

Comparison between Jigging Closely Sized and Mixed Feeds. - Devaney and Coghill35/ state:

> The sized feed is the only kind that is metallurgically correct. When the ore is difficult, that is, when the mineral is only moderately heavier than the gangue, the feed should be sized between limiting screens with openings that have a ratio not greater than 1:1 1/2. To do otherwise is to violate natural laws for expediency.*** The jigging of manganese ores is most satisfactory when the feed is sized.

Rate of Feed to Jigs. - A uniform rate of feed to jigs of all types is essential to their effective operation. In most of the older plants jigs are fed directly with screened portions of log-washer concentrate just as it comes from the log washer. As the log washers are fed irregularly with bank ore and as the amount of concentrate produced from a ton of the log-washer feed varies widely, the feed to the jigs is very irregular. Consequently, the work done by jigs fed in this manner is only partly effective.

In this respect the design of the two plants in northeastern Tennessee is particularly noteworthy. These plants provide adequate storage for jig feed, and the feed from the storage bins to the jigs is carefully controlled, so that the rate will be uniform for any desired amount.

Water Supply

An adequate supply of water is one of the most important factors in determining the feasibility of treating ore from any Appalachian manganese deposit and in selecting the location of the treatment plant.

As stated, 1 to 8 tons of water is needed for each ton of bank ore fed to a log washer. The source of supply of the water need not be particularly close to the manganese-ore deposit. The bank ore can be trucked relatively cheaply for a considerable distance; likewise the water can be pumped and elevated some distance at a reasonable cost. The location of the plant should represent an economic balance between the cost of trucking ore and that of pumping the water to treat it.

35/ Hewett, D. F., Stose, G. W., Katz, F. J., and Miser, H. D., Possibilities for Manganese Ore on Certain Undeveloped Tracts in Shenandoah Valley, Va.; Geol. Survey Bull. 660-J, 1918, pp. 271-304.

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Another important factor in plant location which is often given scant consideration is tailing disposal. In the Cartersville district water usually is reclaimed from tailing ponds and used again in the log washers. Crane[36] states that in this manner as much as 75 percent of the water required by a plant can be reclaimed so that only 25 percent fresh water need be supplied.

Tailing Disposal

Disposal of tailing is exceedingly important. As the laws of most States prohibit the dumping of tailing from washing plants directly into streams and as at some plants it is necessary to conserve the water supply, settling ponds or basins are used for tailing.

Settling ponds usually are made by constructing earth dams across small stream valleys or building crescent-shaped dams on a gently sloping hillside. By spreading the tailing over a fairly large area most of the solid matter settles. At some plants two or more ponds may be required.

Where no attempt is made to reclaim water a wooden sluice gate is built in the earth dam to carry off the overflow of clear water. By adding boards to this sluice gate the height of the clear-water overflow can be increased gradually as the tailing builds up.

Where water is reclaimed, as in the Cartersville district, a wood box is set in the pond, and the suction line to the pump is placed in it. As the top of the box is open, a shallow current of clear water flows into it. Boards are added as the tailing builds up.

CONCLUSIONS

1. Manganese-ore deposits in the Shady dolomite formation are widespread throughout the Appalachian region, and their aggregate available tonnage of ore undoubtedly is large. Most deposits are small but possibilities appear good for finding other large deposits, such as the deposit at Crimora, Va. A careful exploratory campaign and laboratory ore testing would be required to select a desirable deposit for exploitation.

2. Simple ore-treatment processes, now practiced in the Appalachian region, will produce finished concentrate of different manganese content, depending on the completeness of the work of nature, that is, the completeness with which the clay has been replaced by the manganese-bearing solutions. These simple processes remove clay and visible cherty silica but not the remaining waste constituents intimately distributed mechanically throughout the individual nodules; moreover, they cannot eliminate iron or phosphorus.

3. A moderate-size, well designed plant, based upon adequate preliminary exploration and ore testing and using simple ore-treatment processes as well as modern, factory-built equipment, can operate at a profit under present manganese-ore prices if it has sound management and careful engineering, accounting, and analytical control. Such a plant, with a capacity of approxi-

36/ See footnote 34.

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mately 10,000 long tons of finished concentrate a year, would require an investment of about $60,000 for plant and equipment, preliminary exploration and engineering services.

4. Several mining and washing plants at individual properties in one general area would be more effective. The log-washer concentrate from the washing plants could be trucked to a central concentrating plant where jigging, tabling, and possibly more complicated methods of treatment could be applied. This combination would stand better the overhead cost of proper management and a selling organization. Possibly, different grades of ore could be blended to give a more desirable finished concentrate.

5. The extent to which these products could be used by the steel and chemical industries would depend on the acuteness of the demand for manganese and the availability of higher-grade imported manganese ore; however, if steel plants could be assured of a constant supply of concentrate of uniform grade, a greater tonnage might be marketed from the Appalachian region.

6. The application of more complicated processes of treatment, such as magnetic separation or flotation, to manganese ore of this type presents not only technical but also economic problems that are outside the scope of this paper.

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